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AIR FORCE

HUMAN RESOURCES

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AIRCREW TRAINING DEVICES: FIDELITY FEATURES

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Logistics Research Branch
Wright-Patterson Air Force Base, Ohio 45433

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Final Report

LABORATORY

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235

NOTICE

This final report was submitted by Canyon Research Group, Inc., 741 Lakefield Road, Suite B, Westlake Village, California 91361 under Contract F33615-77-C-0067, Project 1710, with the Logistics and Technical Training Division, Air Force Human Resources Laboratory (AFSC), Wright-Patterson Air Force Base, Ohio 45433. Mr. Bertram W. Cream was the Contract Monitor for the Laboratory.

This technical report has been reviewed and is approved for publication.

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This report presents relationships between aircrew training requirements and aircrew training device (ATD) fidelity features and degrees of fidelity. Research and operational experience information was used. Fidelity refers to the degree to which cue and response characteristics of ATDs allow for the learning and practice of specific training tasks. Visual system fidelity is addressed from the standpoints of visual system physical design and training effectiveness. Platform motion systems and their relationship to training effectiveness, efficiency and user acceptance are addressed. The design and use of force cueing devices (e.g. G-seats and arm loaders) and their relationship to platform motion and visual system cues are discussed. A conceptual training effectiveness framework is presented for use in assessing the training value of motion and

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- training efficiency
- training requirements
- transfer of training
- user acceptance
- visual simulation
- visual system fidelity

Item 20 (Continued)

force cueing. Flight characteristics fidelity, or the reproduction of aircraft control and response characteristics in an ATD, is examined to determine instructional values of having an ATD "feel" like its aircraft counterpart. A conceptual framework is presented to guide training decisions about the need for high flight characteristics fidelity. The interaction of visual and motion system cues is discussed in terms of effects on training and performance of delays between related cues.

PREFACE

This report describes a portion of a study of Air Force aircrew training using simulation as one part of a total training system. The study was initiated in response to a Request for Personnel Research (RPR-77-9) from Headquarters, USAF (AF/XOOTD).

This is one of seven technical reports prepared for the Air Force Human Resources Laboratory, Logistics and Technical Training Division, under Contract F33615-77-C-0067, Simulator Training Requirements and Effectiveness Study (STRES). The reports are identified in Chapter II of this document.

The work was performed from August 1977 through February 1980 by a team made up of Canyon Research Group, Inc.; Seville Research Corporation; and United Airlines Flight Training Center. Canyon Research Group, Inc. was the prime contractor; Mr. Clarence A. Semple was the Program Manager. The Seville Research Corporation effort was headed by Dr. Paul W. Caro. The United Airlines effort was headed initially by Mr. Dale L. Seay and subsequently by Mr. Kenneth E. Allbee.

Mr. Bertram W. Cream was the AFHRL/AS Program Manager. Other key members of the AFHRL/AS technical team included Dr. Thomas Eggemeier and Dr. Gary Klein. A tri-service STRES Advisory Team participated in guiding and monitoring the work performed during this contract to assure its operational relevance and utility. Organizational members of the Advisory Team were:

Headquarters, USAF
Headquarters, Air Training Command
Headquarters, Tactical Air Command
Headquarters, Strategic Air Command
Headquarters, Military Airlift Command
Headquarters, Aerospace Defense Command
Headquarters, Air Force Systems Command
Tactical Air Command, Tactical Air Warfare Center
Air Force Human Resources Laboratory
USAF Aeronautical Systems Division
Air Force Test and Evaluation Center
Air Force Manpower and Personnel Center
Air Force Office of Scientific Research
Navy Training Analysis and Evaluation Group
Army Research Institute for the Behavioral and Social Sciences

The authors wish to express their gratitude to the hundreds of people in the United States Air Force, Navy, Army, Coast Guard, NASA, FAA and industry who contributed to this program by providing technical data and participating in interviews and technical discussions during program data collection.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

Chapter | Page

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION

The U.S. Military services have been users of flight training devices and simulators for over half a century. These training media, known collectively as aircrew training devices (ATD), include cockpit familiarization and procedure trainers, part-task trainers, operational flight trainers, weapon systems trainers, and full mission trainers. In recent years, use of ATDs has increased to the point that the devices represent major aircrew training resources, and their effective and efficient design and use is a matter of continuing concern.

In response to this concern, the U.S. Air Force undertook a programmatic study of factors involved in ATD design, use, cost and worth. This program was titled Simulator Training Requirements and Effectiveness Study (STRES). The general objectives of STRES are to define, describe, collect, analyze and document information bearing on the cost and training effectiveness of flight simulators. Topic areas covered in the program are: ATD fidelity features; instructional support features; utilization; life cycle costs; and worth of ownership. Products of the program are intended for use by those who manage and use simulators for training, evaluate simulator requirements, design, procure, and maintain these devices. Chapter II describes the STRES effort in more detail.

This volume is one of seven prepared during the STRES program. It addresses issues related to ATD fidelity features and training effectiveness. Other volumes prepared during the program are identified in Chapter II.

BACKGROUND

The history of flight simulation has been one of constant technological improvements. Most of these have focused on improving fidelity. As a result, modern digital flight simulators look, feel and respond more like their aircraft counterparts than ever before. One effect has been improved acceptance of simulators by instructors and students.

An effectively designed training simulator, however, is one that not only promotes user acceptance, but also takes advantage of the unique training opportunities that can be provided through simulation. ATDs offer freedom from many of the instructional constraints associated with aircraft as training devices. Instructional efficiencies can be obtained. Performance assessment opportunities are improved. And, new tactics can be evaluated and trained, which might not be possible in the air.

PURPOSE OF THIS REPORT

The purpose of this report is to present information dealing with relationships between simulator fidelity features and training effectiveness for specific training tasks. The tasks specified for this effort were:

- Individual and formation takeoff and landing;
- Close formation flight and trail formation, both close and extended;
- Aerobatics;
- Spin, stall and unusual attitude recognition, prevention and recovery;
- Low level terrain following flight;
- Air refueling;
- Air to air combat (guns and missiles); and
- Air to ground weapon delivery.

Content of this report is based on a review of uses and limitations of currently installed fidelity features and a review of the professional literature. The review of available operational and professional information was extensive. However, the issue of ATD fidelity for training historically has been a topic where opinions are strong, but solid evidence is weak or lacking. Furthermore, the fidelity feature issues selected by the Air Force to be addressed in this study were chosen in part because available information often is inadequate and additional research is needed. One thrust of this report, therefore, is to assemble and integrate what is known, relate that knowledge to known information needs, and determine where information shortfalls exist. Thus, this report presents available knowledge on ATD fidelity in relation to aircrew training effectiveness and efficiency, and also identifies information shortfalls to alert users of the report to potential risk areas and to guide future research.

This report was prepared for use by personnel who are responsible for the design and use of ATDs. These personnel include training program developers, those tasked with developing ATD specifications, rated and nonrated ATD instructors, flight and ATD training supervisors, unit management personnel, and personnel responsible for assessing and controlling the quality of ATD training. Others for whom this report was prepared include personnel in higher management positions who are concerned with the effectiveness of ATD training.

It must be recognized that such a large target audiance requires a level of writing and detail different from usual technical or scientific reports. A conscious effort has been made to present facts, conclusions and guidance in a clear, straightfoward manner. The use of technical jargon has been avoided wherever possible. It has not been possible, however, to completely avoid this problem. Therefore, this volume contains a glossary of special terms used within it.

ROLES OF ATDs

The advantage of any training device is its isolation from real world problems and constraints. These may involve costs, time constraints, tactical or strategic constraints, safety problems, environmental factors, lack of aircraft, an unacceptable instructional environment, or combinations of these and similar factors. Properly designed and used, ATDs offer ways around many of these problems, or offer ways of minimizing the training impacts of operational problems and constraints. However, it must be recognized from the outset that ATDs are not total substitutes for inflight training and task exposure. Nor are they substitutes for other training methods and media, ranging from platform lecture and self study to audio visual presentations. Rather, ATDs are one of the training tools at the training manager's d-isposal. The issues are: how ATDs can be best designed and used to support training for combat mission readiness; and how ATD fidelity influences training effectiveness.

TRAINING REQUIREMENTS AND OBJECTIVES

It is becoming more common to read and hear about training being geared toward specific ends. These ends are determined through analysis and are documented so that, theoretically, training is systematically and efficiently directed at meeting them. Many terms commonly are used to describe these ends. Two such terms are used in this report. They are defined in this section so that their meanings in this document are clear.

The term "training requirements" is used in two ways. One is a general statement of job performance skills that are required for aircrew members to be operationally proficient, but which they cannot perform adequately at the beginning of training. This meaning has particular application in undergraduate and transition training. A second meaning is a general statement of job performance skills that require continued practice to maintain proficiency. This meaning is more relevant to continuation training.

Training objectives, on the other hand, are more precise statements of the goals of training. By way of example, a training requirement for individual approach and landing would involve a number of more specific training objectives. One objective, for example, could require a TACAN

approach to a GCA pickup, followed by a GCA final approach. In addition, training objectives set forth the performance standards that are to be met, and the conditions under which the performance is to be demonstrated.

Training objectives do not have to be limited to job performance skills, such as a TACAN approach. They also can be developed as intermediate, or learning objectives where steps leading to operational job performance are identified. Detailed analyses at this level seldom precede ATD designs. Yet, it is at this level where much ATD training is focused.

TRAINING EFFECTIVENESS

At the final level, training effectiveness is training benefit gained in terms of combat mission readiness. In a general sense, ATD effectiveness is the satisfaction of some portion of overall aircrew training requirements. That is, ATDs, with their associated curricula (instructional programs), are effective if they can produce and/or maintain portions of overall aircrew skill requirements, preferably stated as training requirements and/or training objectives.

The concept of transfer of training is central to training effectiveness. Transfer of training is the carry forward of what is learned in one setting to performance in a different setting. An example is the transfer of a skill learned in an ATD to performance in an aircraft. *Positive transfer means that a benefit was gained.* No transfer means no benefit was gained; and negative transfer means what was learned and carried forward actually interfered with performance. Transfer usually is thought of in terms of performance. However, transfer also can involve confidence, attitude and other subjective factors.

Transfer of training and training effectiveness are general concepts. Their application is not limited to gaining combat mission readiness, although this remains the ultimate objective. For example, academic study of air combat tactics can transfer positively to learning how to perform the tactics in an ATD. Performance in the ATD, in turn, may transfer positively to performance of the maneuvers in the aircraft.

TRAINING EFFICIENCY

Training efficiency refers to resource investments required to achieve specific training objectives or requirements. Resources may include time, instructor assets, ATD assets, aircraft assets and costs. Training efficiency is directly related to training effectiveness. There can be no efficiency if there is no effectiveness, because effectiveness implies a benefit gained from the resources invested.

THE FIDELITY ISSUE

Fidelity is an illusive word that means different things to different people. Training devices are referred to as having high or low fidelity as though fidelity can be evaluated along some single scale. No such scale is known to exist; and none is used in this volume. Yet, a generally held assumption among operational users is that high fidelity is necessary for training effectiveness and efficiency.

A fundamental problem underlying the fidelity issue is that fidelity is approached in general, rather than specific terms. One result is that the training to be supported by the ATD often is defined only in very general terms. As a consequence many requirements documents fail to provide specific, logically supported statements of actual training requirements and objectives. The failure to adequately define specific objectives and the necessary performance criteria to judge success of training program graduates are major causes of problems throughout the ATD procurement and operational life cycle. In addition, clear operational concepts for using new ATDs seldom exist at the time of their design. As a result, their training roles in a total program context cannot be considered in detail or objectively during the design stage.

These factors make it very difficult to meaningfully identify training-related cue, response and feedback capabilities required in the ATD. Also, the stage is not set to objectively examine legitimate requirements to depart from corresponding aircraft physical and operational characteristics in order to improve the training value of the device being designed. All tools needed to do this properly are not available. Until structured research and development provide such guidance, many ATDs will continue to be designed simply to mimic (or attempt to mimic) their aircraft counterparts, independent of a carefully considered role as a training tool.

Associating ATD fidelity requirements strictly with operational realism can result in ATD design shortcomings. For example, early computer generated imagery (CIG) out of cockpit visual systems presented images mathematically patterned very precisely after the real world. It was found that this approach did not provide necessary psychological cues for precisely controlled flight in the simulator. The visual scene had to be stylized (a departure from reality) to provide the psychological cues needed for pilot acceptance and to enable precision flight control the simulator. Another component of the realism approach to fidelity is in the concept that the student station must be an exact physical and operational replica of the airborne workstation, and further, that all crewstation controls and displays must be present and operate just as they would in the airborne environment, independent of considerations of training uses of the device.

An ATD is a training tool, not an operational system. In many cases it is counter productive to impose design goals or limits on a training tool that stem from aircraft design. Aircraft must be designed with respect to weight, aerodynamics and certain safety factors. ATDs are free of these constraints. Yet, many ATD designs do not take advantage of these freedoms. They also ignore the fact that, instructionally, it often is sound practice to vary from mimicking the operational device (and its limitations) in order to make training more productive. Fidelity for training must be viewed in the context of what learning is to take place on the ground, how this will benefit (transfer to) airborne operational performance, and needs (or lack of needs) for ATD fidelity in these contexts.

TASK FIDELITY

Task fidelity is a concept that cuts at least part way through the ATD realism issue. The premise of task fidelity is that an ATD needs to provide the cues, opportunities for student responses, and instructional capabilities that are appropriate to specific training objectives. This relates directly to the Instructional System Development (ISD) approach to training program and device design.

There are many different methods currently being employed by the military services under the title of ISD. Although many of the methods have some value, a fundamental problem has been that military personnel tasked with doing ISD analyses are not properly grounded in the specific methods and overall goals of ISD. Typically, learning about ISD has been a bootstrap effort, and by the time the process is reasonably understood, the people involved are transferred to other assignments. Also, ISD emphasizes final job performance rather than the process of learning what is to be done. The present technology of ISD lends itself more readily to the analysis of highly proceduralized performance. Procedural performance is relatively easy to describe and to train. Problem analysis and decision making, on the other hand, are much more difficult to analyze and train. Improved analysis methods are needed so that ATD design and use can be geared better to student learning and practice needs, rather than just operational system characteristics and uses.

The concept of task fidelity requires an understanding and analysis of training device cue and response capabilities needed to support learning and practicing tasks that lead to or involve combat performance. The details of such a learning task analysis remain to be worked out. At a minimum, however, questions pertaining to final skills defined in terms of task performance, conditions surrounding performance, and performance standards, as well as learning steps involved in achieving the skills, all must be addressed.

These are not easy issues, and answers become more difficult as training requirements become more complex. This volume does not provide

all of the needed answers. It does present baseline information focused on what is known today about relationships between ATD fidelity and training for the operationally oriented tasks listed previously. These tasks are the training requirements addressed in this report. The report also identifies and discusses issues that require research programs beyond the scope of the present effort. These issues are combined and presented in a separate report titled: Future Research Plans. This report and others prepared during the present effort are fully identified in Chapter II.

ATD FIDELITY

The following definition of fidelity is used in this volume: ATD fidelity is the degree to which cue and response capabilities in a simulator allow for the learning and practice of specific tasks so that what is learned in the device will enhance performance of these tasks in the operational environment.

Combining this definition of ATD fidelity with the concept of task fidelity greatly simplifies the issue of "how much" ATD fidelity is required for effective training, because fidelity requirements are directly linked to the training to be provided. This focuses fidelity needs on specific training objectives and processes, and avoids the pitfall of attempting to specify fidelity in an abstract, general way based solely on aircraft characteristics.

REPORT ORGANIZATION

Separate chapters of this report deal with individual fidelity issues. Chapter III addresses out of cockpit visual system design and effectiveness. Chapter IV deals with flight characteristics fidelity. Chapter V addresses platform motion systems, and Chapter VI deals with force cuing devices (G-seats, G-suits, etc.). Chapter VII addresses the issue of synchronizing cues provided through platform motion systems, force cuing devices and visual simulations. In each of these chapters, training issues are presented. Research data and operational experience information are brought together. Conclusions are then made regarding the fidelity feature and training effectiveness for the training requirements that provided focus for this program.

CHAPTER II

THE STRES PROGRAM

INTRODUCTION

Aircrew training is an expensive and time consuming endeavor. At one time or another, virtually every known training method and medium has been used to develop operationally ready aircrews and to maintain their skill levels. To meet these training needs in a cost effecctive manner, the U.S. Military has shown increased interest in the use of simulators and related training devices. These training media, known collectively as aircrew training devices (ATD), include cockpit familiarization and procedures trainers, part-task trainers, operational flight trainers, weapon systems trainers, and full mission trainers.

Recent requirements to economize on aircraft fuel used for training have provided strong impetus for the increased interest in ATDs, but other factors have contributed as well. These other factors include increasingly congested airspace, safety during training, cost of operational equipment used for training, and a desire to capitalize on training opportunities that ATDs provide for training that cannot be undertaken effectively, safely or economically in the air.

Because of the advantages simulation can offer over other aircrew training media, it is current Air Force policy that ATDs will be used to the fullest extent to improve readiness, operational capability and training efficiency. Implementation of this policy requires specific technical guidance. Information upon which to base that guidance is sparse, however, and the information that does exist is not always available to those who need it. The STRES program was intended as a means of identifying and making available ATD design, use, cost and worth information to support relevant Air Force policies. The information is intended to provide guidance for the enhancement of present training, as well as for the focus of research and development needed to enhance future simulation-based training.

PROGRAM STRUCTURE

The primary objectives of the overall STRES program are to define, describe, collect, analyze and document information bearing on four key areas. The areas are:

> Criteria for matching training requirements with ATD fidelity features;
>
> Criteria for matching ATD instructional features with specific training requirements;

Principles of effective and efficient utilization of ATDs to accomplish specific training requirements; and

Models of factors influencing the life cycle cost and worth of ownership of ATDs.

The Air Force plan for accomplishing these objectives involves a four-phase effort. Phase I, which was concluded prior to the initiation of the present study, was an Air Force planning activity to define and prioritize the total effort. Phase II, the effort described in the series of reports identified below, was a 29 month study that involved collecting, integrating, and presenting currently available scientific, technical, and operational information applicable to specific aircrew training issues. Phase II also involved the identification of research and development efforts needed to enhance future simulator training. Phase II was conducted by a team composed of Canyon Research Group, Inc., Seville Research Corporation, and United Airlines Flight Training Center. Phase III is planned to be a research activity that will provide additional information on important simulation and simulator training questions that cannot be answered with currently available data. Finally, building on Phases II and III, Phase IV is planned as an Air Force effort to integrate findings, publish relevant information, and provide for updating of the knowledge base as new information becomes available.

A tri-service Advisory Team was formed by the Air Force to help guide STRES. The team has participated in two ways. One was to assist in the Phase I program planning. The second has been to provide guidance and evaluative feedback during Phase II to ensure that products of the phase would be operationally relevant and useful. Both operational users of ATDs and the research community were represented on the Advisory Team.

A principal task of the Advisory Team was to participate in the development of objectives and guidelines for the conduct of the Phase II technical effort. As a focus for those efforts, a set of "high value" operational tasks was identified. The tasks selected were those for which potential ATD training benefits were judged to be greatest, and for which information on ATD design, retrofit, use, and worth was believed to be incomplete or lacking. These tasks also provided a focus for identifying questions and issues reflecting the information needs of operational personnel that were to be addressed during Phase II efforts. The high value tasks identified by the Advisory Team are:

Individual and formation takeoff and landing;

Close formation flight and trail formation, both close and extended;

Aerobatics;

Spin, stall and unusual attitude recognition, prevention and recovery;

Low level terrain following flight;

Air refueling;

Air-to-air combat (guns and missiles); and

Air-to-ground weapons delivery.

SOURCES OF INFORMATION

Information from two sources was collected during Phase II to address the objectives of STRES. One source was the professional and technical literature. This literature included books, conference proceedings, professional journals, research reports, military manuals and regulations, and policy statements. The second source was military and civilian personnel whose experiences related to the objectives of the study. Information was obtained from these personnel during visits to organizations to which they were assigned.

Literature Review

Computer searches were made at the outset to identify literature relevant to all facets of the Phase II effort. In addition, each contractor team member was responsible for identifying documents pertinent to his responsibilities that may have been missed in the computer searches. In these individual efforts, articles pertinent to the various activities of colleagues were regularly encountered. Each investigator was aware of the information needs of his colleagues, and frequent communication among team members assured that colleagues would be apprised of articles of potential value to their tasks. Hence, the search for literature of concern to the preparation of a given volume of the STRES report series, while systematically complied by those specifically responsible for that volume, was expanded through the efforts of the entire team.

To provide integration and focus to these literature search efforts, one group of the STRES team was specifically responsible for identifying articles of potential interest to all team efforts, as well as for preparing comprehensive abstracts of selected documents that appeared particularly valuable. These abstracts appear in a separate volume of the STRES report series.

More than 1,100 documents were identified during these efforts as potentially relevant. These were further screened according to the currency and completeness of information provided and the integrity of

the experimental and analytic methods used. As a result of this screening, approximately 400 documents were found to be useful for STRES purposes.

Site Visits

A considerable body of information also was obtained from organizations, both government and commercial, whose personnel are involved in the design, procurement, evaluation, management, and use of ATDs. ATD manufacturers, research and development agencies, and a commercial airline were visited in addition to Air Force, Army, Navy, and Coast Guard military training sites. At each organization, extensive data were obtained through observations, interviews, and document reviews. The training organizations visited and the topics of primary interest at each are listed in Table 1. Table 2 lists non-training organizations that were visited and corresponding interest topics.

Specific objectives of the interviews and other data collection efforts varied, depending on the type of organization visited and the purpose of the visit. Manufacturers and research and development agencies were visited to assess current and projected technology and to review ongoing and planned efforts bearing on STRES program objectives. ATD using organizations were visited to obtain a variety of information related to types and effectiveness of training accomplished, uses of various types of devices in accomplishing the training, ATD design characteristics, worth of ATD ownership, and ATD life cycle costs. Detailed interview guides were used.

STRES PHASE II REPORTS

Seven reports were prepared to document Phase II efforts and findings. They are:

Semple, C.A., Hennessy, R.T., Sanders, M.S., Cross, B.K., Beith, B.H., & McCauley, M.E. Aircrew Training Devices: Fidelity Features. AFHRL-TR-80-36. Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory, January 1981.

Semple, C.A., Cotton, J.C., & Sullivan, D.J. Aircrew Training Devices: Instructional Support Features. AFHRL-TR-80-58. Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory, January 1981.

Caro, P.W., Shelnutt, J.B., & Spears, W.D. Aircrew Training Devices: Utilization. AFHRL-TR-80-35. Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory, January 1981.

Table 1. Training Sites Included In Program Surveys

Sites and Units	Topics of Interest
Altus AFB, OK (MAC) 443rd Military Airlift Wing	C-5 transition training
Castle AFB, CA (SAC) 93rd Bomb Wing	KC-135/B-52 transition training
Denver, CO United Air Lines Flight Training Center	DC-10/B-737/B-747 transition and continuation training
Eglin AFB, FL (TAC) 33rd Tactical Fighter Wing	F-4 continuation training
Fort Rucker, AL US Army Aviation Center	UH-1/CH-47 undergraduate and transition training
Langley AFB, VA (TAC) 1st Tactical Fighter Wing	F-15 continuation training
Mobile, AL US Coast Guard Aviation Training Center	HH-3/HH-52 transition and continuation training
NAS Cecil Field, FL VA-174 and Light Attack Air Wing One	A-7E transition and continuation training
NAS Jacksonville, FL VP-30 and Patrol Wing Eleven	P-3C transition and continuation training
Plattsburgh AFB, NY (SAC) 380th Bomb Wing	FB-111 transition training
Reese AFB, TX (ATC) 64th Flying Training Wing	T-37/T-38 undergraduate pilot training
Tinker AFB, OK (TAC) 552nd Airborne Warning and Control Wing	E-3A transition and continuation training

Table 2. Sites Visited For Management, Research, Development, Engineering and Cost Surveys

Sites and Agencies	Topics of Interest
Pentagon Headquarters, USAF	Management of Air Force ATD resources, and life cycle costs
Randolph AFB Headquarters, ATC	Management of the use of ATDs in undergraduate pilot training, and life cycle costs
Langley AFB, VA Headquarters, TAC	Management of the use of ATDs in fighter aircrew training, development of ATD requirements, and life cycle costs
Eglin AFB, FL (TAC) Tactical Air Warfare Center	Procurement, development and evaluation of ATDs
Luke AFB, AZ (TAC) 4444th Operational Training Development Squadron	Development of training and ATD requirements
Williams AFB, AZ Air Force Human Resources Laboratory (AFHRL/FT)	ATD research
Wright-Patterson AFB, OH Air Force Human Resources Laboratory (AFHRL/AS)	ATD research
Fort Rucker, AL US Army Research Institute for the Behavioral and Social Sciences	ATD research
NASA Langley Research Center Langley, VA	ATD research
McDonnell Douglas Corp. St. Louis, MO	ATD design and research
Singer-Link Corp. Binghampton, NY	ATD design, procurement and evaluation
Navy Training Analysis and Evaluation Group Orlando, FL	ATD research and life cycle costs

Table 2. - (Continued)

Sites and Agencies	Topics of Interest
Naval Training Equipment Center, Orlando, FL	ATD research and life cycle costs
Navy Personnel Research and Development Center San Diego, CA	ATD research and life cycle costs
US Army Project Manager for Training Devices (PM-TRADE) Orlando, FL	ATD research and life cycle costs
Hill AFB, UT (AFLC)	ATD life cycle costs
Hollomon AFB, NM (AFTEC)	ATD life cycle costs
Luke AFB, AZ (TAC)	ATD life cycle costs
Offutt AFB, NE (SAC)	ATD life cycle costs
Scott AFB, IL (MAC)	ATD life cycle costs
Travis AFB, CA (MAC)	ATD life cycle costs
Williams AFB, AZ (ATC)	ATD life cycle costs
Wright-Patterson AFB, OH (ASD)	ATD engineering and life cycle costs

Allbee, K.E., & Semple, C.A. Aircrew Training Devices: Life Cycle Cost and Worth of Ownership. AFHRL-TR-80-34. Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory, January 1981.

Prophet, W.W., Shelnutt, J.B., & Spears, W.D. Simulator Training Requirements and Effectiveness Study (STRES): Future Research Plans. AFHRL-TR-80-37. Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory, January 1981.

Spears, W.D., Sheppard, H.J., Roush, M.D., & Richetti, C.L. Simulator Training Requirements and Effectiveness Study (STRES): Abstract Bibliography. AFHRL-TR-80-38. Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory, January 1981.

Semple, C.A Simulator Training Requirements and Effectiveness Study (STRES): Executive Summary. AFHRL-TR-80-63. Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory, January 1981.

The content of the first four of these reports, i.e., ATD fidelity, instructional features, utilization, and cost and worth of ownership, is interrelated. As an aid to the reader in accessing related information, these four reports were cross-referenced. Within a single volume, other chapters where related information is discussed are referenced. When the cross-referenced information is in another volume, that volume is identified by abbreviated title (Fidelity, Instructional Features, Utilization, or Cost) as well as by chapter. For example, Utilization, Chapter IV, would indicate that related information will be found in Chapter IV of the report titled Utilization of Aircrew Training Devices. As an additional aid to the reader, the Executive Summary volume reproduces the tables of content of all four technical volumes to provide a consolidated listing of topics addressed in each.

APPROACH TO THE FIDELITY FEATURES SURVEY

Literature Review

Articles identified during the literature search were screened for relevance to ATD fidelity. The screening was not restricted to the immediate domain of this report, however, for the perspective needed to answer questions related to fidelity frequently required knowledge of broader issues such as the nature of the training being undertaken, student entry level skills, and transfer of training to inflight tasks. Also, information concerned primarily with phenomena and principles of learning and related instructional practices was needed for a comprehensive assessment of ATD fidelity requirements.

Site Visit Activities

Activities of study team members responsible for the fidelity area during visits to sites identified in Table 1 included inspection of available simulators and related training aids, and observation of demonstrations of pertinent aspects of their capabilities and use. The majority of time was spent, however, in intensive interviews with instructors involved in ATD use, and pilots undergoing training. Additionally, maintenance personnel were interviewed on ATD reliability, maintainability and hardware/software design features that might influence device fidelity. A detailed interview guide was used, and notes were recorded during and following the interviews. The interview guide is shown in Appendix A.

Interviews with key personnel also were the principal information gathering technique employed during visits to the sites indicated in Table 2. The thrust of visits to sites shown in Table 2, however, was to obtain information about research in progress or planned, advanced simulation technology, and present and anticipated regulatory requirements and policies that could influence future ATD training programs. Information gained from these sources also broadened the perspective from which practices at training sites could be viewed.

Hardware and Software Configuration Data

Attempts were made during initial site visits to collect data on engineering design characteristics of ATD computing, motion and visual systems. The objective was to examine relationships between hardware/software characteristics and training advantages or limitations of devices included in the survey. The practice was dropped, with Air Force concurrence, after initial site visits for three reasons: 1) Much of the information sought was not available; 2) Examination of information that could be obtained showed no relationship to ATD use or acceptance; and 3) Much of the technology surveyed was out of date by current standards, making the information questionable for future applications.

The following listing summarizes information sought initially, but not throughout program site visits.

<u>ATD mean time between failures and mean time to repair</u>. Summary data were not available at sites visited. Military ATD down time and lingering maintenance problems are not now the problem they used to be. Military ATD maintenance now appears to be generally comparable with airline ATD maintenance. A majority of ATDs surveyed was available for training 16 to 20 hours per day, five to six days per week.

<u>Spares requirements</u>. Specific spares problems, when encountered, varied considerably among ATDs, as would be expected. Two trends

were consistent, however, where spares problems were encountered: 1) When ATDs used aircraft parts, such as instruments, aircraft were given preference when parts were scarce; and 2) Many parts are no longer available off the shelf for older ATDs and must be specially manufactured.

Platform motion systems. Most often, information on motion system maximum excursions, velocities, accelerations, and hardware bandwidths was unavailable. Where available, it existed only in the original ATD design specification, and there never is assurance that actual performance, particularly after several years of use, meets an original specification.

ATD computing characteristics. These include: basic machine cycle time; iteration rates; memory size; word length; addressable memory range; addressing modes; total length of operations (in words) of real time software; and methods of internal fetching and execution of instructions. Although some of this information could be obtained, much could not. Also, much reflected out of date technology, and bore no discernible relationship to training effectiveness or ATD acceptance.

Visual system modulation transfer functions. This information was not available.

Planned ATD modifications. Only major modifications, such as adding an out of cockpit visual system, could be identified at training sites. Details of these and other planned changes were not available.

Types of safety and fire protection systems installed. The military simulator facilities visited almost completely lacked fire protection systems. Safety egress systems for ATDs consisted of ropes or ramps for exiting the ATD in an emergency. Fire exit signs were not used to guide students or instructors out of the facilities.

CHAPTER III

VISUAL SYSTEM FIDELITY

SUMMARY

Visual systems providing an out of cockpit view are considered necessary for ATD training of contact flying skills. Research studies and operational experience support the position that training in visually equipped ATDs will transfer in a beneficial way to performance in the aircraft for many tasks. However, available scientific and operational information provides little useful guidance on how to design ATD visual systems to maximize training effectiveness.

Research and operational experience with visually equipped ATDs indicate, rather solidly, that training in such devices will transfer (carry forward) to inflight performance for the following tasks: individual aircraft approach and landing; and contact flight. It can be said with some confidence that ATD training likely will transfer positively for: stall recognition, prevention and recovery; formation flight; air refueling; and air to ground weapons delivery. No conclusions about transfer of training can be made for aerobatics or air to air combat tasks.

Visual system technology is relatively new and experience with it is limited. Therefore, the following issues remain unclear at this time: 1) how to best use visually-equipped ATDs; 2) effects of instructional variables, such as instructor location; 3) their use for skill maintenance; 4) effects of pilot aptitude level; 5) effects of pilot experience level; and 6) effects of visual system characteristics.

The last issue is a considerable problem because science has not been able to produce a useable model of human visual perception in complex tasks. As a result, presently there is no objective way of relating details of the visual scene (e.g. field of view, resolution, color, texture and scene content) to the process of human information extraction and use. Such a model is needed to replace speculation and subjectivity in visual system design with perceptually-centered design guidelines that can be related to training effectiveness.

TRAINING EFFECTIVENESS INFORMATION

Introduction

This section presents results of experiments and observations of training effectiveness of ATDs which incorporate simulated external visual scenes. The measure of training effectiveness is defined in terms of transfer of training.

Transfer of training is demonstrated by comparing real world performance in an aircraft of a group trained in an ATD with performance of a group receiving no ATD training. If the ATD-trained group performs better than the untrained group, positive transfer is demonstrated and the ATD is considered to be of value for training the task under consideration. If there is no difference between the simulator-trained and untrained groups, then no transfer has been demonstrated and the ATD is considered to be of no value for training the tasks. In most cases where no tranfer is found, there are differences between the simulator and untrained groups but the differences are not statistically reliable. That is, there is a fair chance (typically one in twenty) that the difference could have been due to chance factors such as chance differences in skills of each pilot group. If the simulator-trained group actually performs worse than the untrained group, negative transfer is demonstrated. In such cases, ATD training is actually causing a disruption in performance. Negative transfer, however, is quite rare in the context of flight simulation training.

Available Data

A review of the flight simulation literature was conducted to locate documents which meet the following criteria: 1) The performance of simulator trained subjects was evaluated during actual aircraft flight. Studies which only measured performance in the simulator were not included. Differences in simulator performance may not "transfer" to actual flight conditions. Since the focus of this section is on transfer, simulator-only studies were not included. 2) The task being trained involved out of cockpit visual reference and the simulator incorporated external visual scenes. This excluded, for example, transfer studies dealing only with instrument flight.

The use of these criteria also excluded consideration of the issue of the synchronizing sensor imagery (e.g. radar, LLLTV and IR) with out of cockpit visual imagery. The importance of this issue is recognized, because unsynchronized visually displayed information can result in cue conflicts that can degrade learning and performance. This issue, however, is beyond the scope of the present discussion.

Using the criteria described above, a total of only 21 studies was found. There are two principal reasons why such a small number of studies exist. First, there are few research organizations that have simulators which can generate external visual scenes, and these have not been in use very long. Second, it is difficult and expensive to measure performance in actual flight, which is required in a transfer of training experiment.

A few comments concerning the published literature are in order before reviewing the relevant research. First, studies addressing a particular flying task differ along many dimensions. For example, subject population, simulator used, aircraft involved, training methods

used, and scoring techniques often are different from study to study. Unless results are consistent across studies, it is not possible to isolate the critical factors which contribute to or inhibit transfer effectivenes. Second, the published literature often does not fully report all necessary details of the study. Therefore, comparisons among studies are made more difficult.

Also, it seems that researchers, in the quest for experimental control or the need to complete the experiment, sometimes create situations that work to minimize training effectiveness. For example, Jacobs and Roscoe (1975) stated that they did not allow individualized training or "other techniques of training for maximum transfer" in the interest of uniform experimental treatment. Young, et al. (1973) said their instructors complained of lack of training time and that students had no chance to learn basic skills; yet the study was run to completion. Pohlmann and Reed (1978) similarly indicated that "instructing the student . . . was not attempted because of the limited visual feedback available to the instructor." It should be no surprise, then, that neither Young nor Pohlmann and Reed were able to demonstrate any transfer in their studies. Woodruff, et al. (1976) had instructors located at a remote console instructing UPT students in the cockpit. As expected, they found only slight amounts of transfer.

The methodology used in a training effectiveness experiment is, in many respects, analogous with the instructional methods used in comparable ATD training. It is likely that information which is considerably more meaningful could be obtained in the future if methods and constraints associated with classic laboratory experimentation were abandoned in favor of methodologically sound, but more operationally relevant experimental practices.

Measures of Performance

The studies isolated for review in this section used various measures of inflight performance. Two major classes of measures can be defined: 1) subjective ratings of performance, usually made by flight instructors; and 2) objective measures of performance such as bombing accuracy, final position in air combat, or contacting the boom during air refueling.

Subjective ratings are far and away the most common method of measuring performance in the air because they are the easiest to do. There is reason to believe, however, that subjective ratings may be unreliable and/or insensitive to differences in performance between ATD-trained and untrained groups. Five studies (Semple, 1974; Payne et al., 1976; Gray and Fuller, 1977; Browning, Ryan and Scott, 1977; and Browning, Ryan and Scott 1978) found no transfer using subjective ratings, but on the same tasks, found substantial positive transfer when objective measures of performance were used. Brictson and Burger (1976), although finding positive transfer for both subjective and

objective measures, found substantially higher positive transfer with objective measures. This must be kept in mind when interpreting studies which use only subjective ratings and fail to find positive transfer. The failure may be due to the lack of sensitivity of the measures used rather than the training received.

Minimum Conditions for Transfer

There are two minimum conditions for transfer to occur: 1) something actually must be learned in the ATD; and 2) whatever is learned must have some application to the inflight task. Therefore, when no transfer is found, one must ask whether any learning of relevant skills took place in the ATD. As obvious as this may be, there are several studies (which will be discussed) which indicate that no training in the ATD was attempted, or that although attempted, conditions prevailed which made it impossible to train the students.

Transfer Effectiveness Ratio

The 21 transfer of training studies reviewed addressed different training tasks, involved different simulators, used different training methods, and measured performance in different ways. To facilitate comparisons among studies, a simple metric of transfer effectiveness was computed within each study where the necessary data were available. The measure is percent transfer (Ellis, 1965) and is defined by the formula:

$$\text{Percent transfer} = \frac{\Delta\,(S,C)}{C}$$

Where: $\Delta\,(S,C)$ = the difference in inflight performance between the simulator (S) trained group and the untrained control (C) group, and where positive values indicate superior performance for the S group;

C = inflight performance of the control group; and

S = inflight performance of the simulator-trained group.

A percent transfer, for example, of 40% indicates that the inflight performance of the simulator-trained group was 40% better than the inflight performance of the untrained control group. Although Ellis defined other measures of transfer, their interpretation is not as clear as percent transfer.

ORGANIZATION OF TRAINING EFFECTIVENESS INFORMATION

The balance of this section is organized to address specific training issues related to the training value of simulated external

visual scenes. Each training issue is presented as a question, and what little relevant information exists is reviewed in an attempt to answer the question.

The research literature consists of relatively few studies, and those that do exist have little in common with each other. Interview information obtained during program site visits was largely impressionistic. At only one site was any attempt found to objectively verify subjective feelings about the training values of ATD visual systems. Therefore, the reader should not expect to find many detailed, specific conclusions regarding the training issues to be addressed.

To answer the training issues that are raised will require systematic programs of transfer of training research in which visual system, task and training method variables are systematically manipulated, and transfer is objectively measured. Such programmatic research on visual system design and use simply does not exist at this time. Most of the studies are "one-shot" attempts to evaluate a particular simulator for training a particular task. A few studies of visual systems also compared motion base and no-motion base trained groups. Only one such study, however, also varied visual scene parameters and measured transfer in flight. From the state of information available, general conlusions are hard to come by.

The following visual task training issues are addressed in this balance of this section:

For which visual flight tasks does ATD training demonstrate positive transfer?

What visual system characteristics are important for transfer?

How do instructional variables influence ATD effectiveness?

Can visually equipped ATDs be used to maintain skill levels of trained pilots?

How does student aptitude level influence ATD training effectiveness?

How does student experience level influence ATD training effectiveness?

For Which Visual Flight Tasks Does ATD Training Demonstrate Positive Transfer?

An exhaustive search of the simulation literature uncovered 21 studies which evaluated the training effectiveness of particular visual flight simulators. Each study compared groups of students trained in an

ATD and similar groups not trained in an ATD. Performance of both groups was measured in an aircraft and then compared. Findings from these studies, along with informtion obtained from on site interviews, are organized by training tasks and summarized in Table 3 through 10. The same study is referenced for more than one training task if more than one task was trained and evaluated. There are fewer than three entries for all but two of the flight tasks. The exceptions are approach and landing with 11 entries and contact flight with five entries.

The following sections discuss each program task and attempt to make conclusions where they seem warranted. Trends are identified where they appear to exist.

Approach and Landing. Eight out of 11 experimental studies showed positive transfer ranging from 16% to 84%, depending on the specific task being measured. One of the three studies which showed no transfer (Young, Jensen and Treschel, 1973) noted that the training received by the students in the ATD was poor. Instructors complained that there was inadequate time given in the ATD for training and that the ATD training came too early, before students had a chance to learn basic flying skills. Thus the lack of transfer found in this case may be a result of the training received rather than the nature of the visual simulation used or the tasks trained.

The second study which showed no transfer for approach and landing used visual pretraining only, rather than an interactive flight simulator (Edwards, Weyer and Smith, 1978). In visual pretraining, UPT students were presented with, in the case of this study, wide angle slide photographs of the normal turn flight path and slides showing varying deviations from the normal final approach flight path. The presentations took place in a classroom setting. This study also had method problems which may account for the lack of positive transfer. Due to scheduling difficulties, a number of students performed landings at a field other than the one used in the visual pretraining. This second field involved right-hand patterns, while the pretraining used standard left-hand patterns. Further, the ground references were different at the two fields. To quote the authors: "Obviously pretraining on ground references at one field will not help the student land an aircraft at another field", at least during early training.

The third study (Bynum, 1978) which shows no transfer used an experimental night visual system added to a rotary wing ATD. The system was plagued with hardware reliability problems. The visual system also made it difficult to judge distances and altitude. Artifical altitude and rate of closure cues (not present in real aircraft flight) were added. In addition to these hardware problems, students participating did so as an extra assignment, in addition to their normal training. No attempt was made to integrate their simulation training into the total

REFERENCE	SUBJECT POPULATION	SIMULATOR/ SIMULATED AIRCRAFT	TRANSFER AIRCRAFT	MOTION BASE	VISUAL SYSTEM CHARACTERISTICS
Brictson and Burger; 1976	Novice (320-330 jet hrs) Experienced (1140-1290 jet hrs)	Night Carrier Landing Trainer (NCLT) A-7E	A-7E	Yes (3df)	Computer generate FOV = 40° horizon 30° vertical, col picture of deck 1 collimating lense
Edwards, Weyer, and Smith; 1978	Novice	Visual pre-training T-37	T-37	No	Wide angle cockpi views (slides) of maneuver
Flexman, et al; 1972	No previous flight experience	1-CA-2 SNJ Link Trainer SNJ-4	SNJ-4	Yes (2df)	Stationary pictur ground and horizo Instructor drew c line on blackboar tracing flight pa a map of airfiel
Lintern and Roscoe; 1978	Novice	Singer link general aviation simulator	Piper Cherokee Arrow	Yes (2df)	Computer generat Advent videobeam TV square plasma display screen
Martin and Waag; 1978b	Novice (13-80 hrs)	Advanced Simulator For Pilot Training (ASPT) T-37	T-37	Yes (6df)	Computer generat Seven CRT displa full infinity op
Smith, Waters and Edwards; 1975	Novice	Visual pre-training	T-37	No	Sound slide and pictures
Young, Jensen, and Treschel; 1973	Novice	Not given	Not given	Not given	Runway and color
On-site interviews	Novice UPT's	UPT/IFS T-37	T-37	Yes	Model board visu color, infinity

Table 3. Approach and Landing: Sum
Training Effectiveness Inf

M ICS	TYPE OF MEASURES	SPECIFIC TASK TRAINED	PERCENT TRANSFER	COMMENTS
erated display, rizontal and , colored eck lights, lenses	Objective	Night boarding rate Carrier qualification attrition	19% 81%	Only novice pilots showed positive transfer
	Súbjective ratings	Night Landing	16%	
ockpit s) of	Subjective ratings	Overhead landing pattern approach	None	Some students trained on left hand patterns but tested at right hand pattern airport
icture of orizon line. rew chalk kboard ht path over field	Trials to criterion, time to reach criterion, errors	Entry into traffic pattern Flying traffic pattern	68-74% 57-84%	None
erated display. beam 70 x 53 in asma matrix en	Subjective ratings Objective	Landing performance Unassisted landings	48% 13.7%	Severely limited detail in visual field
erated display. splays FOV = y optics	Subjective ratings	Straight in approach Straight in landing Overhead pattern	18% 17% 24%	Instructor can not see visual display in front of aircraft
and 8mm movie	Trials to criterion	Overhead pattern	16%	None
olored horizon	Subjective	Successful landings	None	Visual system disappeared at flare point, instructors complained of too little time allotted for training
visual system, ity optics	Objective	First unassisted approach and landing	73%	Simulator visual makes it appear plane is landing above the runway

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s Summary of
s Information

	CONCLUSIONS
ed	Positive transfer demonstrated for novice pilots only
on	Detailed visual pretraining may not be timely at an early phase of training
	Positive transfer demonstrated
ll	Positive transfer demonstrated
e it	Positive transfer demonstrated
	Positive transfer demonstrated
red uctors tle ining	Poor instruction precludes meaningful conclusion
s it ng	Positive transfer demonstrated

REFERENCE	SUBJECT POPULATION	SIMULATOR/ SIMULATED AIRCRAFT	TRANSFER AIRCRAFT	MOTION BASE	VISUAL SYSTEM CHARACTERISTICS
Browning, Ryan, and Scott; 1978	Novice (first tour Naval aviators)	2F87F P-3 Orion	P-3 Orion	Yes (6df)	Model board TV syst FOV = 50° horizonta 38° vertical, varia visibility, darknes ceiling.
Ryan, Scott, and Browning; 1978	Novice (first tour Naval aviators)	2F87F P-3 Orion	P-3 Orion	Yes (6df)	Model board TV syst FOV = 50° horizonta 38° vertical, varia visibility, darknes ceiling
Bynum; 1978	Student pilots (No night flight experience)	APO Night Visual Calligraphic IR&D Product Improvement System UH-1H Helicopter	UH-1H Helicopter	Yes (5df)	3 window display (2 and 1 side) compute generated image. field of view. Al and rate of closur added.

Table 3. (continued)

AL SYSTEM ACTERISTICS	TYPE OF MEASURES	SPECIFIC TASK TRAINED	PERCENT TRANSFER	COMMENTS
l board TV system. = 50^{o} horizontal, vertical, variable bility, darkness, ing.	Subjective grades	Approach and landing	None	None
	Flight hours to criterion		43%	
	Landings to proficiency		66%	
l board TV system. = 50^{o} horizontal, vertical, variable ibility, darkness, ling	Subjective grades	Landing tasks only (Normal, approach flap, 3 engine)	None	Lack of peripheral vision and poor depth perception with visu system
	Flight hours to criterion		36-43%	
	Landings to proficiency		44-66%	
indow display (2 front 1 side) computer erated image. Narrow ld of view. Altitude rate of closure cues ed.	Subjective ratings	Night approach and landing	None	This was an experime visual system. Plag with reliability pro visual system caused difficulty in judgin distances and altitu Artificial cues adde display to facilitat judgements.
	Trials to criterion		None	

	CONCLUSIONS
	Positive transfer demonstrated
	Positive transfer demonstrated
al d ems, s. to	No transfer demonstrated

/38

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REFERENCE	SUBJECT POPULATION	SIMULATOR/ SIMULATED AIRCRAFT	TRANSFER AIRCRAFT	MOTION BASE	VISUAL SYSTEM CHARACTERISTICS
Flexman, et al; 1972	No previous flight experience	1-CA-2 SNJ Link Trainer SNJ-4	SNJ-4	Yes (2df)	Stationary pictur ground and horizo line
Jacobs and Roscoe; 1975	No flight experience	Singer Link GAT-2 Piper Cherokee	Piper Cherokee Arrow	Yes	Not discussed
Martin and Waag; 1978b	Novice (13-80 hrs)	ASPT T-37	T-37	Yes (6df)	Computer generate Seven CRT display full, infinity op
Woodruff and Smith; 1974	No flight experience	T-4G T-37	T-37	Yes (2df)	Film base visual FOV = 44° x 28°
Woodruff, et al; 1976	Less than 50 hrs flight experience	ASPT T-37	T-37	Yes (6df)	Computer generate 36" diameter CRT display, FOV = ± horizontal, +75° vertical, infini

Table 4. Contact F
Effective

VISUAL SYSTEM CHARACTERISTICS	TYPE OF MEASURES	SPECIFIC TASK TRAINED	PERCENT TRANSFER	CO
Stationary picture of ground and horizon line	Trials to criterion, time to criterion, errors	All contact work	55-69%	N
Not discussed	Trials to criterion	11 Maneuvers (not specified)	41-56%	[illegible]
Computer generated display. Seven CRT displays, FOV = full, infinity optics	Subjective ratings	Take off Slow flight	20% 46%	Instructor visual dis of aircraf
Film base visual system, FOV = 44° x 28°	Time to criterion	Basic contact flight	Average 3 hrs savings in aircraft by using simulator	[illegible]
Computer generated display. 36" diameter CRT, 7 window display, FOV = ± 150° horizontal, +75°-20° vertical, infinity optics	Time to criterion	Basic contact flight Advanced contact flight	45% 4%	Instructor external c not see st visual dis schedule p time was g Advanced C

Table 4. Contact Flight: Summary of Training Effectiveness Information

CENT NSFER	COMMENTS	CONCLUSIONS
-69%	None	Positive transfer demonstrated
-56%	None	Positive transfer demonstrated
% %	Instructor can not see visual display in front of aircraft	Positive transfer demonstrated
rage rs ings in craft using ulator	None	Positive transfer demonstrated
% %	Instructors seated at external console could not see students or visual display. Due to schedule problem less time was given for Advanced Contact Flight	Positive transfer demonstrated

3

REFERENCE	SUBJECT POPULATION	SIMULATOR/ SIMULATED AIRCRAFT	TRANSFER AIRCRAFT	MOTION BASE	VISUAL SYSTEM CHARACTERISTICS
Flexman, et al; 1972	No previous flight experience	1-CA-2 SNJ Link Trainer SNJ-4	SNJ-4	Yes (2df)	Stationary pict ground and hori line
Martin and Waag; 1978b	Novice (13-80 hrs)	ASPT T-37	T-37	Yes (6df)	Computer genera Seven CRT displ full, infinity

Table 5. Sta[...]
Effe[...]

N	VISUAL SYSTEM CHARACTERISTICS	TYPE OF MEASURES	SPECIFIC TASK TRAINED	PERCENT TRANSFER	
)	Stationary picture of ground and horizon line	Trials to criterion, time to reach criterion, errors	Stall recovery	48-67%	
)	Computer generated display. Seven CRT displays, FOV = full, infinity optics	Subjective ratings	Power in stalls Traffic pattern stalls	24% 25%	Instr[...] visua[...] of ai[...]

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Table 5. Stall Recovery: Summary of Training Effectiveness Information

PERCENT TRANSFER	COMMENTS	CONCLUSIONS
48-67%	None	Positive transfer demonstrated
24% 25%	Instructor can not see visual display in front of aircraft	Positive transfer demonstrated

3

REFERENCE	SUBJECT POPULATION	SIMULATOR/ SIMULATED AIRCRAFT	TRANSFER AIRCRAFT	MOTION BASE	VISUAL SYSTEM CHARACTERISTICS
Reed and Reed; 1978	"Undergoing initial qualification in F-4C"	Air Refueling Director Lights Trainer	F-4C	No	Presents receiver director lights on underside of tanker No distance cues.
On-site interviews	Minimum 1600 hrs flight time	Engineering simulator approximating C-5 handling characteristics	C-5	No	Black and white ima of tanker and boom. FOV = $\pm$ 60° horizon $\pm$ 40° vertical

Table 6. A
E

OTION ASE	VISUAL SYSTEM CHARACTERISTICS	TYPE OF MEASURES	SPECIFIC TASK TRAINED	PERCENT TRANSFER	
o	Presents receiver director lights on underside of tanker. No distance cues.	Subjective ratings	Air refueling	Not specified	Posi only
o	Black and white image of tanker and boom. FOV = $\pm$ 60° horizontal, $\pm$ 40° vertical	Objective	Making contact Maintaining contact	300% 2300%	Mark firs flig

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Table 6. Air Refueling: Summary of Training Effectiveness Information

...SK TRAINED	PERCENT TRANSFER	COMMENTS	CONCLUSIONS
...ng	Not specified	Positive transfer found only on first mission	Positive transfer demonstrated
...act ... contact	300% 2300%	Marked improvement during first two refueling flights	Positive transfer demonstrated

3

REFERENCE	SUBJECT POPULATION	SIMULATOR/ SIMULATED AIRCRAFT	TRANSFER AIRCRAFT	MOTION BASE	VISUAL SYSTEM CHARACTERISTICS
Reid and Cyrus; 1974	110 hrs experience	Formation Flight Trainer T-38	T-38		Wide angle project TV picture of lead aircraft
Woodruff, et al; 1976	Less than 50 hrs experience	ASPT T-37	T-37	Yes (6df)	Computer generated 36" diameter CRT, display, FOV = ± 1 horizontal, + 75-2 vertical, infinity

Table 7. F
E

…TION …SE	VISUAL SYSTEM CHARACTERISTICS	TYPE OF MEASURES	SPECIFIC TASK TRAINED	PERCENT TRANSFER	
	Wide angle projected TV picture of lead aircraft	Subjective ratings	Formation flight	15-23%	Inst… craf…
…es …6df)	Computer generated display. 36" diameter CRT, 7 window display, FOV = $\pm$ 150° horizontal, + 75-20° vertical, infinity optics	Time to criterion	Formation flight	13%	Form… prac… simu… disp…

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Table 7. Formation Flight: Summary of Training Effectiveness Information

TRAINED	PERCENT TRANSFER	COMMENTS	CONCLUSIONS
ht	15-23%	Instructor flew lead aircraft from console	Positive transfer demonstrated
ht	13%	Formation flight not practiced much in simulator due to visual display problems	Positive transfer demonstrated

3

REFERENCE	SUBJECT POPULATION	SIMULATOR/ SIMULATED AIRCRAFT	TRANSFER AIRCRAFT	MOTION BASE	VISUAL SYSTEM CHARACTERISTICS
Gray and Fuller; 1977	UPT graduates 250-275 hrs experience	ASPT T-37	F-5B	Yes (6df)	Seven 36 in. mono-chromatic CRT's. $+110^{\circ}$ to -40° ver and $\pm 150^{\circ}$ horizon infinity optics

Table 8. Air to
of Tra

	VISUAL SYSTEM CHARACTERISTICS	TYPE OF MEASURE	SPECIFIC TASK TRAINED	PERCENT TRANSFER	C
	Seven 36 in. monochromatic CRT's. FOV = + 110° to -40° vertical, and ± 150° horizontal, infinity optics	Objective	10° dive, circular error	28%	No differ transfer aptitude
			15° dive, circular error	21%	
			30° dive, circular error	19%	
			Qualifying bombs	70%	
		Subjective ratings	Overall flying performance in bombing pattern	None	

2

Table 8. Air to Ground Weapon Delivery: Summary of Training Effectiveness Information

RAINED	PERCENT TRANSFER	COMMENT	CONCLUSIONS
lar	28%	No difference in amount of transfer for high and low aptitude students	Positive transfer demonstrated (even though simulator was configured as T-37 and transfer was measured in F-5B)
lar	21%		
lar	19%		
s	70%		
	None		

3

REFERENCE	SUBJECT POPULATION	SIMULATOR/ SIMULATED AIRCRAFT	TRANSFER AIRCRAFT	MOTION BASE	VISUAL SYSTEM CHARACTERISTICS
Martin and Waag; 1978a	Novice: No previous flight experience	ASPT T-37	T-37	Yes (6df)	Seven 36 in. monochromatic CRT's. + 110° to -40° ver and ± 150° horizon infinity optics

Table 9. Aer
Eff

ON	VISUAL SYSTEM CHARACTERISTICS	TYPE OF MEASURES	SPECIFIC TASK TRAINED	PERCENT TRANSFER	
)	Seven 36 in. monochromatic CRT's. FOV = + 110° to -40° vertical, and ± 150° horizontal, infinity optics	Subjective ratings	Aileron Roll Split S Loop Lazy 8 Immelman Bank & Roll Cuban 8 Clover Leaf	None None None None None 34-58% None None	1. Aerob empha 2. Simul alway contr feren not s relia 3. Impro forme analy when analy tical

2

Table 9. Aerobatics: Summary of Training Effectiveness Information

...ED	PERCENT TRANSFER	COMMENTS	CONCLUSIONS
	None None None None None 34-58% None None	1. Aerobatics are not emphasized in training 2. Simulator trained group always superior to control group but differences were usually not statistically reliable 3. Improper analysis performed. Univariate analysis were performed when multivariate analysis was not statistically significant	No positive transfer demonstrated

3

REFERENCE	SUBJECT POPULATION	SIMULATOR/ SIMULATED AIRCRAFT	TRANSFER AIRCRAFT	MOTION BASE	VISUAL SYSTEM CHARACTERISTICS
Payne, et al; 1976	UPT graduated with 350 flight hrs and experienced pilots with more than 1200 hrs	Northrop Air to Air Combat Simulator (LAS/WAVS) F-4J	F-4J	Yes	Visual projectio of earth sky ima maneuverable adv aircraft, hemisp screen surroundi half of cockpit FOV)
Pohlmann and Reed; 1978	Receiving initial F-4 training (flight hours not specified)	Simulator for Air to Air Combat (SAAC) F-4	F-4	Yes (6df)	Matrix of 8 pent CRT windows. FO 296° x 150°. Sy terrain generato camera model air image generator

Table 10.

ON	VISUAL SYSTEM CHARACTERISTICS	TYPE OF MEASURES	SPECIFIC TASK TRAINED	PERCENT TRANSFER	
	Visual projection system of earth sky images and maneuverable adversary aircraft, hemispherical screen surrounding front half of cockpit (210° FOV)	Subjective ratings	Lag Pursuit Lag Roll High Yo Yo Low Yo Yo Barrel Roll attack Rolling Scissors Head-on maneuvering Guns Defense	None None None None None 38% None None	Visual anomal real
		Objective	Final position after engagement	23-96%	
)	Matrix of 8 pentagonal CRT windows. FOV = 296° x 150°. Synthetic terrain generator and camera model aircraft image generator	Subjective ratings	Acceleration maneuver High Yo Yo Quarter plane Barrel Roll attack Immelman attack Log Roll Separation Tactical Formation Step up on perch Defense maneuvers	None None None None None None None None None None	Instr was n of th feedb instr

Table 10. Air to Air Combat: Summary of Training Effectiveness Information

PERCENT TRANSFER	COMMENTS	CONCLUSIONS
None None None None None 38% None None 23-96%	Visual system had several anomalies not found in the real world	Positive transfer demonstrated for objective measures only
None None None None None None None None None None	Instructing the students was not attempted because of the limited visual feedback available to the instructor	No positive transfer demonstrated

3

training context. It is possible that these factors contributed to the lack of transfer found.

In summary, eight out of 11 approach and landing studies demonstrated positive transfer, and the three other studies suffered from problems which cast doubt on the validity of their findings. In light of the eight affirmative studies, each using different students, aircraft, training methods and simulators, it can be said with a good deal of confidence that the proper use of visually equipped ATDs results in positive transfer of training for the individual approach and landing task in fixed wing aircraft.

Contact Flight. Each of the five studies showed at least 40% transfer on elements of contact flight. It can be said with a good deal of confidence that visually equipped ATDs, properly used, result in positive transfer for contact flight.

Stall Recovery. Only two studies were found that specifically addressed stall recovery. Although both used different students, aircraft, ATDs and training methods, they both showed positive transfer ranging from 24% to 67%. With only two studies, however, it is not practical to place a great deal of confidence in any conclusion. At the time program site visits were made, the Air Force was just beginning to use the UPT/IFS ATD for undergraduate pilot training. Use of this visually equipped device for stall recognition, prevention and recovery was being explored, but even preliminary opinion on the effectiveness of the training had not been formed. Therefore, it can be said with only some confidence that ATD training likely results in positive transfer for stall recovery performance.

Formation Flight. Only two studies addressed transfer for formation flight. Both, however, showed moderate amounts of positive transfer (13% to 27% percent). Woodruff et al., (1976) reported the lowest percent transfer of the two studies, but they point out that due to visual system problems with the ATD (parts of the lead aircraft selectively disappeared when the image generation system became overloaded) formation flight training was limited to only two simulated flights. Thus, the low percent transfer may be due to a lack of training opportunity. With only two studies, it can be said only with some confidence that ATD training likely results in positive transfer for formation flight performance. This conclusion is supported, however, by evidence of effective C-5 air refueling training in a visually equipped simulator. Air refueling requires close formation flight.

Air Refueling. Only one published study could be found addressing air refueling (Reed and Reed, 1978). This study used a table-top trainer which simulated the air refueling director lights displayed on the underside of the tanker aircraft. The device presented the pilots with no distance or closure rate cues, but only demonstrated the proper

control responses to be made to the varying director light patterns. The authors stated that postive transfer was evident only on the first of two inflight refueling missions. On the second flight, pilots who had received director light training performed no different from those who had not.

Program interviews with C-5 instructors indicated that they had found much better performance on air refueling from pilots trained at a contractor simulator facility than from pilots trained before the simulator training program was started. The instructors indicated that before simulator training, initial contacts with the tanker aircraft lasted only ten to 15 seconds. Following simulator training, initial contacts of ten minutes were common. Also, following simulator training the numbers of contacts during initial inflight training tripled. These results are impressive, but without a controlled experiment in which people making up the groups are carefully equated, one cannot make a conclusion regarding air refueling with a great deal of confidence. It can be said with some confidence, however, that proper use of a visually equipped ATD will result in positive transfer for training the air refueling task.

Air to Ground Weapon Delivery. Only one study was found which investigated transfer for air to ground weapons delivery (Gray and Fuller, 1977). Positive transfer was demonstrated on all measures of bombing accuracy. The consistency of results across measures leads us to conclude with some confidence that training in the ASPT simulator most likely results in positive transfer for air to ground weapon delivery.

Aerobatics. Only one study (Martin and Waag 1978a) addressed transfer for aerobatics. Although the simulator-trained group was superior to the control group on all eight aerobatic maneuvers, the difference were not statistically reliable on seven of the eight maneuvers. Martin and Waag state, however, that aerobatics are not really stressed in Air Force T-37 UPT training, and this lack of emphasis during simulator training may account for the lack of clean cut (statistically reliable) differences. Based on this, no conclusion can be made about the transfer effectiveness of simulator training for aerobatics. Additional studies will have to be done before a conclusion can be made.

Air to Air Combat. The only two studies addressing one versus one air to air combat showed virtually no transfer on individual maneuvers when performance was evaluated by instructor pilots using subjective ratings of quality. In contrast, Payne et al., (1976) did show positive transfer when the more objectively scored "final position" was used as the criterion. This may indicate that instructor ratings are not a sensitive or reliable measure of transfer for highly complex, multi-faceted maneuvers such as those found in air to air combat.

Simulator training in the Payne et al. study was done in a research simulator with a dome-type visual system.

Further, Pohlmann and Reed (1978) indicated that: "Instructing the students . . . was not attempted because of limited visual feedback (about the students' performance) available to the instructor". Thus, the lack of positive transfer they found may have been due to an inability to train transitioning pilots in the Simulator for Air to Air Combat (SAAC), and not to the visual simulation itself.

Instructors who use the SAAC device in the Air Force TAC-ACES program hold the opinion that the SAAC is a useful tool for pilots to refine basic skills they already have in one versus one and two versus one air combat. However, there are no objective data to verify this opinion or establish the amount and type of positive transfer that may be expected. A certain percentage of pilots flying the SAAC in the TAC-ACES program also report disorientation following sessions in the device. This issue is under investigation by the Air Force. However, no such disorientation was reported by pilots who participated in the air combat study reported by Payne et al. (1976), which involved use of a dome-type visual projection system and a large amplitude motion system.

An additional comment is warranted about the use of visually equipped ATDs for basic air combat maneuvering training. Navy instructor pilots who served as ATD instructors in the study reported by Payne et al. commented on several occasions that being away from the pressures of normal daily duties made it possible for instructors and the pilots being trained to talk about one versus one air combat throughout the day and well into the evening hours. (Instructors and students were TDY to the Northrop Corporation during the study.) Essentially, therefore, intense and lengthy periods of verbal instruction were possible during the study. Such instruction was not possible during normal training. It was the collective opinion of the instructors that these opportunities for indepth discussions of air tactics may have been as valuable as the simulator training that was provided. Chalk and Wasserman (1976) report similar instructor comments in the context of TAC-ACES training done at Vought Corporation's simulator facility. Future research should attempt to isolate the effects of this (extensive verbal instruction) variable, because it may provide important guidance on the type of academic training that must accompany hands-on training in air combat simulators.

With only two studies addressing air to air combat, one in which no instruction was attempted, and both of which relied heavily on subjective instructor ratings of complex maneuvers, no conclusion about the value of simulators for training basic air to air combat skills can be made. More research will have to be done before a conclusion can be made regarding either basic skill acquisition or maintenance.

Summary. It can be said with a great deal of confidence that visually equipped ATDs, properly used, result in positive transfer for individual aircraft approach and landing, and contact flight training. It can be said with some confidence that ATD training likely will result in positive transfer for stall recognition, prevention and recovery; formation flight; air refueling; and air to ground weapons delivery. No conclusions about transfer of ATD training can be made for aerobatics and air to air combat.

What Visual System Characteristics Are Important For Transfer?

Given the current, limited state of knowledge about the training effectiveness of specific visual system parameters, it is not possible to specify the necessary and sufficient conditions required for positive transfer. There simply are not enough transfer studies available to discern any patterns with regard to training impacts of specific visual system parameters, such as: resolution; color; infinity versus real images; field of view; and combinations of these and others. There are numerous dimensions and combinations of dimensions along which visual systems can vary. However, there are only 21 transfer studies upon which to base answers. And, only one study (Thorpe, et al., 1978) directly compared different visual systems for the same task. Further, almost all of these studies show similar degrees of positive transfer, even though they used different simulators with different visual system characteristics. With such a small number of studies, all showing similar levels of transfer, it is impossible to isolate any specific out of cockpit visual system characteristics which contribute to or inhibit transfer for the tasks studied.

A thorough review of the transfer literature points to one very solid conclusion: High fidelity, 100% realism, is not required in a visual system in order to achieve positive transfer from a properly used device. Evidence for this conclusion comes from three sources: 1) a transfer study that compared different visual systems on the same task; 2) studies which did not use high fidelity, 100% realistic visual displays; and 3) anecdotal evidence and opinions of instructors, pilots and transfer study researchers. Each of these lines of evidence is addressed below.

The reader is advised that much of the information which follows involves transition and continuation training for rather routine flight tasks. No research was found dealing specifically with either undergraduate training or tactical or strategic mission training.

Different Visual Systems. Only one study (Thorpe, et al., 1978) was located which compared transfer performance of groups of pilots trained with simulators using different visual systems. The problem with interpreting studies such as this is that visual system characteristics are not independent. That is, when one characteristic is altered, usually several others also are changed. Thus, if a difference in

transfer effectiveness is found between the systems, it is impossible to determine from the results what specific characteristics of the systems or their uses caused the effect.

Thorpe et al. compared three visual systems for training CCT students on visual traffic pattern, final approach, and visual landing of a KC-135 aircraft. A day-night color computer generated CIG image system, a night-only point light source CIG system, and a TV/model board system were compared. All three systems had forward and left fields of view only. Each system simulated a different airport and runway as well as different ground cues. Unfortunately, Thorpe et al. did not use a control group trained only in the aircraft. Thus, the amount of transfer for the experimental groups can be assessed only relative to each other. The results indicated somewhat better transfer performance for the day-night color CIG system and the night only point light source CIG system relative to the TV/model board system. These performance differences were reflected primarily in the last two segments of the landing task, and then only on the second of two evaluation flights. There were no statistically significant differences between the day-night and night-only systems. Differences between visual systems accounted for only 15.25% of the total performance variance. This is a very small proportion of variance, especially considering the differences among the visual systems.

A possible explanation for the small effect of the visual display differences on transfer performance may be that the approach and landing task is not sensitive to changes in visual systems. Students learning approach and landing are usually "novices" with relatively little flying experience in training or operational aircraft. The major contribution to positive transfer, therefore, may not be the details of the visual scenes, but rather the experience gained in the basic handling of the aircraft. Thus, until similar research is carried out on more complex tasks, such as formation flying, aerobatics, or air to air combat, we cannot say whether the results of Thorpe et al., apply to tasks other than approach and landing training for transitioning pilots.

Interviews with airline personnel also are of interest here, because a number of airlines use some ATDs incorporating model board visual system technology and some with CIG visual systems. When model board systems first were introduced, they were well received by pilots and were presumed to contribute meaningfully to approach and landing training. Later, when night color CIG systems were installed on other ATDs, pilot acceptance of the older, model board systems soured. Clearly, the image quality of the newer CIG systems is superior to the older technology model board systems. However, a consensus exists, at least within one airline, that either system is equally effective for training and evaluation of performance during final approach and landing.

Use of Low Fidelity Visual Systems. Only three methodologically sound transfer studies were found which used "low fidelity" visual systems. The definition of low or high fidelity in visual systems is complex and arbitrary. The term "low fidelity" is used here to refer to display systems which are "unrealistic" and are not connected directly to simulator actions.

Smith, Waters and Edwards (1975) used visual pre-training consisting of programmed text, sound slide briefings and 8mm motion pictures. The students never "flew" a simulator during pretraining. It was found that the visually pre-trained student reached criterion in the aircraft two flights earlier than did the non-pre-trained students. Flexman, et al., (1972) had subjects fly an SNJ Link trainer while watching an instructor standing off to the side tracing their path with a piece of chalk on a blackboard over a map outline of the airport. The instructor moved the chalk when he saw the simulator move. Apparently no attempt was made to match the movement of the chalk with the speed of the simulated aircraft. Percent transfer ranged from 57% to 84%, which is quite good.

The third study, (Reed and Reed, 1978) investigated air refueling using a table top trainer that presented to students only the receiver director lights on the underside of the tanker. No distance or closure cues were presented. With just one hour practice, they found positive transfer, compared to a control group, on the first actual air refueling mission.

From these studies it appears that rather crude visual displays, properly used, can result in positive transfer. This may, however, again be a function of the specific nature of training the tasks and student skill levels. In all cases, the tasks were basic in nature. Training in flying traffic patterns may be more a function of learning a mental map of the field and general directions for approaching it, rather than specific characteristics of the visual scene. The air refueling table top trainer only trained eye-hand coordination so that students could respond properly to director lights. The positive transfer may have resulted from that, without any need for more sophisticated visual scenes. The results do not indicate that more transfer could not have been achieved if more realistic visual displays had been used; they indicate, however, that whatever was trained with the devices was relevant to the real world tasks to be performed.

Anecdotal Evidence and Opinions. The last source of information comes from comments made by authors of transfer studies in their discussion of results, and from interviews with instructors and other pilots by the project team during site visits to various training organizations. A difficulty with this type of information is that authors and trainers often use visual system characteristics as a scapegoat for lack of transfer. When no transfer is shown and a poor visual system is used, the visual system usually is held responsible. On the other hand, if there are obvious problems with the visual display

and positive transfer is demonstrated anyway, those involved often point out that the transfer occurred in spite of the poor visual system. To make matters worse, both approaches can be used in the same study to "explain" different aspects of the results.

Payne, et al. (1976) listed eight "abnormalities" of the dome-type projection visual system used by them to investigate air combat transfer of training. These included the target aircraft image giving false indications of pitch, yaw and roll; target aircraft oscillations at the limits of the visual system display screen; the target appearing simply as a point of light at greater distances; and the onboard instructor's body blocking some of the student's "outside" view from the cockpit. Despite these and other abnormalities, Payne et al. showed excellent transfer with regard to final position after engagement. Before the fact, many would have predicted that some of these aberrations (especially false target movements and improper distance and aspect cues) should have caused negative transfer in the actual aircraft when fighting a real adversary. Such was not the case, however. Instructors specifically briefed the student pilots on visual system abnormalities to alert them to differences they would find when transferring to the actual air combat situation. They called this "training for transfer". It apparently worked and indicated, possibly, that limitations in visual system can be compensated for by pilots if they are so trained. How far or in what manner the visual system can be degraded and still allow compensation by "training for transfer" is an open question at this time.

Woodruff and Smith (1974) used a basic contact flight simulator with a very small, one window visual system of a limited field of view (44 degrees horizontally and 28 degrees vertically). Despite the limited field of view, they found that the simulator-trained group required three fewer hours in the aircraft to perform maneuvers satisfactorily than did a control group not trained in the ATD. This would indicate that, perhaps for basic contact flight, large fields of view are not necessary. In support of this, Ryan, Scott and Browning (1978) report that instructors believed that they were not obtaining positive transfer from the 2F87F simulator because of a small field of view and poor depth perception cues. The results of the objective transfer study, however, revealed very good positive transfer, despite the views held by the instructors and the small field of view of the simulator. Two studies do not make a fact, however, and more research is needed comparing the effects of different fields of view on transfer performance.

Woodruff, et al. (1976), in an otherwise methodologically sound study, reported difficulties with the visual system of the ASPT research simulator. For example, in formation flying training, when the CIG visual system became overloaded, it selectively dropped out parts of the lead aircraft. "This was most disconcerting to the student who was trying to hold position and to learn to use key reference points (cues) which frequently disappeared". Despite this, it was found that each

hour spent in the simulator on formation flying resulted in one hour savings in the aircraft. In addition, instructor pilots listed several other shortcomings of the visual system, including:

> During the final turn, movement of the runway image from one cathode ray tube to another was not smooth. It jumped somewhat, thereby necessitating unexpected control adjustments which were not characteristic of real-life requirements.
>
> There was insufficient ground detail in the visual environment during the final approach and flare for landing to allow students to adequately judge ground proximity.

Despite these difficulties, they still showed 45% transfer, and that each hour in the simulator saved 0.6 hours in the aircraft for basic contact flying.

The previous studies showed positive transfer despite problems with the visual system. Holman (1978), on the other hand, investigating helicopter flying, found the least amount of transfer (but positive nonetheless) for those maneuvers carried out close to the ground. It was felt that the visual system was at fault. The field of view was too small and the infinity optics visual display could not provide all of the real world depth cues assumed to be used in actual flight to indicate how close an object is to the viewer (e.g., eye convergence or lens accommodations, texture gradients, and size of familiar objects). In like manner, Bynum (1978) found no transfer using a night landing helicopter simulation. Bynum, like Holman, also suggested that the visual system was at fault. The field of view was too small and did not give adequate altitude and rate of closure cues. Thus, at least for close-in work with helicopters, field of view and appropriate depth cues may be important to maximize transfer for "near earth" tasks.

Interviews with Air Force UPT instructor pilots using the T-37 UPT/IFS device revealed visual problems with the simulator. For example, the out of cockpit terrain model board visual display system did not present a ground image above or below 20 degrees of pitch attitude. The simulator lands "high in the air" because of a probe-protect feature designed to prevent the TV probe from hitting the model board. Despite these problems, the average UPT student with ATD training landed the T-37 aircraft without instructor assistance on the sixth or seventh flight, whereas students trained before the UPT/IFS became available required ten to 15 flights before instructors let them land without assistance.

It appears from the evidence that high fidelity, 100% realism, is not necessary to achieve meaningful positive transfer from simulator training, at least for the basic flying tasks that have been studied. Strange anomalies can be present and students still benefit from the training. How far one can go from 100% realism or how strange the

anomalies can become before transfer is compromised cannot be answered based on existing research or experience data. There simply is too little data and too little experience to allow for specifying the necessary and sufficient conditions for transfer on a specific task. Although trite, it must be said that more systematic transfer research is needed to isolate the necessary and sufficient visual conditions for transfer. This appears particularly true for continuation training and tactics training where subtle visual cues may be more meaningful and useful to the skilled pilot.

<u>How Do Instructional Variables Influence ATD Effectiveness?</u>

In the published literature, rarely, if ever, are instructional variables manipulated in pilot-simulator transfer studies. Instructional variables include such things as: physical location of the instructor, syllabus content and structure; relative difficulty of simulator tasks in relation to the actual task in the aircraft; degrees of flexibility afforded instructors in determining training content and time; the use of ATD instructional support features such as freeze and record/replay; and the use of guidance, feedback and mediation as basic training tools. (See Utilization volume, Chapters III and IV)

Ryan, Scott and Browning (1978) conducted one of the few studies which explicitly compared transfer obtained by varying the instructional use of an ATD. The study focused on landing performance in a P-3 Orion aircraft. In addition to the standard no-simulator control group, Ryan et al. included two experimental groups. One group received all their simulator training in one instructional block. The second experimental group received integrated ATD/aircraft training according to a prescribed sequence schedule. The groups were trained the same in all other respects. Results showed that the intergraded training group required 65% more landings to achieve proficiency in the aircraft than did the block-trained group. Unfortunately, a difference in the grading system used for the two groups may account, at least in part, for the difference obtained. For the block-trained group, instructors determined the flight on which students attained proficiency. For the intergraded training group, on the other hand, the training analysis and evaluation group (who conducted the study) determined the flight on which students attained proficiency. It is acknowledged by the authors that differenct performance criteria might have been used for each group. We can, therefore, only say that this result suggests that differential transfer may result from blocked versus intergraded use of ATD and aircraft training. In the case of landing tasks, at least, it might be that blocked presentations result in higher levels of transfer. More research obviously is needed, but the area appears fruitful.

°Thorpe, et al. (1978) suggested that proficiency advancement during ATD training might result in more transfer than simply giving everyone

the same amount of ATD training. The proficiency advancement technique was used by Flexman, et al. (1972) with very good transfer results.

Payne, et al. (1976) suggested that transfer of training would be even better if the task in the simulator is harder to do than it will be in the actual aircraft. Holman (1978), on the other hand, found the opposite to be true.

Although evidence is scant, it appears that a statement made by Thorpe, et al. (1978) probably has much truth in it. There is evidence to suggest that how a training device is used often accounts for more training output (efficiency as well as effectiveness) than the hardware characteristics of the device.

The effective use of ATDs and their instructional features for varying aptitude and skill level pilots involves a complex set of design and instructional issues. The reader is referred to the Instructional Features volume and the Utilization volume for related ATD design and use information.

Can Visually-Equipped ATDs Be Used to Maintain Skill Levels of Trained Pilots?

The Air Force Human Resources Laboratory currently is engaged in a multi-year project with the objective of developing and validating quantitative, objective procedures for managing pilot operational readiness and for supporting flying training requirements (Project SMART). As part of the project, it is planned that alternative skill acquisition, maintenance and reacquisition training programs will be evaluated. The required analytic work is under way at this point.

The STRES literature search of transfer studies employing visually equipped ATDs turned up only one study which specifically addressed the question of maintaining skill levels of trained pilots.

Holman (1978) compared two groups of helicopter pilots on 35 maneuvers. The control group, already trained and qualified, limited its flying during a six month period to mission essential flying only (58 hours). The control group specifically was requested not to fly for training purposes nor to fly other aircraft or flight simulators. The experimental group was treated the same as the control group except it received approximately 30 hours of training in a flight simulator distributed over a four week period. The experimental group flew the aircraft during the period for an average of only 45 hours. A data collection flight was conducted at the beginning and end of the six month period. There was virtually no change in the performance scores of the control group over the six month period. The experimental ATD-trained group, on the other hand, demonstrated statistically significant improvements on 26 of 35 maneuvers. Improvements ranged from 15% to 48% over the pretest scores. The results clearly show, in

this case, that simulator training not only maintained skill levels, but resulted in improvements for trained and qualified helicopter pilots.

It is unfortunate that additional studies have not addressed this issue with respect to other pilot tasks, or similar pilot tasks in other types of aircraft. The generality of Holman's finding cannot be determined. One is left with a tentative conclusion that visually equipped rotary wing ATDs may be useful for skill maintenance of qualified pilots.

How Does Student Aptitude Level Influence ATD Training Effectiveness?

Aptitude levels of pilots must be distinguished from the amount of flight experience they possess. Experience refers to a stage of training or previous flying time of the pilot. Aptitude level, on the other hand, refers to how well the pilot learns to peform tasks at any experience level. The two can be viewed as independent. That is, there are high and low aptitude pilots at any experience level. In essence, experience level refers to what they can do, and aptitude level refers to how well they can learn to do it.

Logical arguments can be made which would predict that either low aptitude pilots would benefit more (i.e., gain larger increases in performance) from ATD training than high aptitude pilots, or that high aptitude pilots would benefit more.

Only one study involving a visually equipped ATD addressed this question in any way (Gray and Fuller, 1977). The authors divided their UPT graduate pilots into two aptitude groups (those above median performance and those below median performance) and measured transfer in air to ground weapons delivery (bombing). The combined group showed significant transfer on objective bomb delivery accurancy scores (from 19% to 70% transfer). A further analysis showed, however, that there was no significant difference in the amount of transfer for high and low aptitude pilots. As expected, the high aptitude pilots in both the ATD-trained and control groups out-performed their low aptitude counterparts; but the difference in performance between the high aptitude ATD-trained and control groups was the same as the difference between the low aptitude ATD-trained and control groups.

With only one study, a definitive response to this issue is not possible. Future transfer studies, as a matter of course, should at least compare high and low aptitude sub-groups even if median performance is used to define high and low. Ideally, a valid aptitude test score should be used to classify students into aptitude sub-groups in future studies.

How Does Experience Level Influence ATD Training Effectiveness?

As discussed in the preceding training issue, experience level defines what a student can do, and is distinguished from aptitude level, which defines how well he can learn to do it.

Visual simulation studies typically have used UPT students or recent UPT graduates. These pilots have had some flying experience but little or no mission-related experience. The experience level of pilots varies from study to study. For example, Reid and Cyrus (1974) used pilots with approximately 110 hours in T-37 and T-38 aircraft in a transfer study using the T-38 aircraft. Payne et al. (1976), on the other hand, used pilots with 350 to over 1,200 hours of prior flight experience. Thorpe et al. (1978) used pilots with over 1,200 hours in aircraft other than the KC-135 used to measure transfer of training. Thus, one might question whether there is an optimal experience level to maximize transfer, and what the effects of experience level on transfer are.

Several studies have alluded to these training issues in the discussion of their results, but without conducting any formal tests. Reid and Cyrus (1974) indicated that positive transfer of formation flying showed up in the early stages of training. Similarly, Martin and Waag (1978b) noted that inspection of their raw data revealed that a majority of training transfer on basic contact maneuvers occurred at the initial state and mid-state of inflight training. Differences between ATD-trained and air-only trained groups washed out later during inflight training. Somewhat opposed to this "early training benefit" argument is the view of Edwards, Weyer and Smith (1978) who found no positive transfer and some evidence of negative transfer for visual pre-training of overhead landing pattern turns. The authors expressed the opinion that: "Detailed visual pre-training may not be timely at an early phase of training when the student is still concerned with instrument references". They support the notion that minimal experience is a necessary condition for effective transfer. However, methodological problems in their study cloud the point.

Brictson and Burger (1976) were the only authors to explicitly address the issue of experience level and ATD training effectiveness. In an A-7E night carrier landing task, two groups of subjects were used: pilots who had no previous A-7E experience but had 322 to 331 jet flying hours; and experienced pilots who had 1100 to 1200 jet hours including carrier landing experience, but had never landed an A-7E on an aircraft carrier. The results showed that only the group with low flying experience showed significant transfer. No statistically reliable transfer was demonstrated for the experienced pilots.

Probably what is important is not experience level by itself, but experience in relation to the skill demands of the task to be learned. If the pilot already knows much or all that proper use of an ATD can

teach, it is not likely that much more will be learned from ATD training.

VISUAL SYSTEM FUNCTIONAL REQUIREMENTS

Introduction

For the purpose of this report, flight simulator visual systems are discussed in relation to their ability to provide a pilot and/or other crewmembers with an out of cockpit view of the world necessary to support training. This section addresses the functional aspects of visual simulation, i.e., those features related to performance. Three general topics are addressed: 1) the literature and knowledge concerning simulator visual systems and visual perception; 2) display characteristics; and 3) scene content, perceptual learning and augmentation.

There are two related ways of specifying visual system requirements. The first is to specify the functional requirements in terms of what the visual system must do to support training requirements. The second is to specify engineering requirements, i.e., physical characteristics of the visual system equipment. Ideally, the engineering requirements would be developed as a consequence of functional training requirements. In practice, however, engineering requirements usually are developed with very minimal information about training functional requirements. Functional requirements for simulator visual systems are very difficult to state.

Limitations of Visual Simulation Knowledge

Simulation of the aircraft environment and the effects of non-visual contacts with the outside world is one thing. Simulation of the visual world itself is quite another. For out-of-cockpit vision, there is no mediation between the pilot and the world. For other environmental effects it is possible to begin simulation at the point where effects are mediated by the aircraft and its systems. Unlike these other environmental effects, there is no mediation between the world and the pilot's eyes where simulation of effects can be applied. To produce a realistic visual simulation of the real world requires modeling of the world itself. Because of the technical impossibility of realistically simulating all aspects of the visual environment, formulation of statements of functional visual system requirements must necessarily involve trade-off decisions about what features will be included or emphasized and what features will be omitted or not emphasized.

A significant problem in defining what the functional visual requirements are for a particular training purpose occurs because the real world is not the same from place to place, i.e. it is not standardized. Different features can provide the same information, i.e., some cues are equivalent and different pilots may use different

cues. The first step in the development of the functional requirements for a visual system should be to determine what is necessary for the training purpose. The typical approach to determining functional requirements for a visual system is to perform an analysis of the flight tasks to be peformed and determine the visual information requirements. It is assumed that the visual information requirements can be specified and will logically lead to the determination of what must be displayed in the scene (i.e., scene content) and the necessary characteristics of the display (i.e., the image quality and performance features of the visual system). Unfortunately this is not usually the case.

A number of previous studies have developed lists of visual information requirements and the visual cues a pilot is assumed to use to perform his tasks (Carel, 1961 and 1965; Havron 1962; Matheny et al., 1971; AGARD, 1972; Stark, 1977; Quanta Systems, 1979). Eventually they arrive at essentially the same conclusion: there is no logical, systematic way of proceeding from visual information requirements to the nature of the picture scene required to provide the information to the pilot. This is largely because there is a considerable gap in the knowledge of visual perception, human information processing and how to characterize visual scenes in terms of providing information to pilots.

The same gap has been encountered before. Carel (1965) had the task of determining the requirements for a pictorial, contact analog display instrument. After examining several lists of pilot information requirements that had been developed in previous studies he conluded:

> "The output of most studies of pilot information requirements is not a total description of pilot information requirements but is a list of information presented by current or proposed instruments or a selection of those parameters that should be displayed in the cockpit for a given system according to the judgments of the investigator".
>
> "One may conclude that lists of pilot information requirements are almost useless as a basis for deciding what information to include in pictorial displays for the pilot. Furthermore it can be argued that even if the information requirements for the pilot were exhaustively known and the required performance for each displayed variable specified numerically, a creative leap is still required to vault the gap between those requirements and the best way of encoding the information. There is no logical or necessary connection between these lists of information requirements and methods of encoding the information."

Accepting the fact that information requirements do not lead logically to functional requirements for scene content and display characteristics, there appears to be two sources of information which might help develop these requirements. These sources are the visual simulation literature and the visual perception literature.

Vision and Visual Simulation Literature

The purpose of this section is to present an overview of the nature of the literature on vision and visual simulation, followed by some general conclusions.

The literature review revealed that remarkably few reports are directly relevant to the development of the functional requirements for simulator visual systems. The reasons for this will be discussed presently. The conclusions reached from the literature review are: 1) the majority of the literature on visual perception deals with basic sensory aspects of vision and the measures of visual space perception, but these contribute little to the understanding of the process of visual information acquisition in support of purposeful, real-world behavior; and 2) there are very few data in the visual simulation literature to aid in determining functional requirements for an ATD visual system.

The Problems Of Using Research Results. Before discussing the nature of the literature on vision and visual simulation it is worth considering an important component of the literature, which is the body of reports presenting data and conclusions derived from research.

Even when there are data that appear relevant to visual simulation, it is often difficult to be confident that the data can be used directly in a current application. This is true of fundamental data and data derived from investigations involving flight simulator visual systems. Few experimental findings can be generalized from the specific experimental circumstances to other aircraft, simulators or training applications. Generalization and acceptance of findings usually occur when several studies conducted under widely differing circumstances come to the same conclusions. Unfortunately there are very few visual topics of importance to visual simulation which have been addressed in more than one study.

Also, a very important consideration in assessing the results of any study is the way performance is measured. For example, in a study of varying levels of texture in a runway visual scene (Buckland, Monroe and Mehrer, 1977) sink rate at touchdown, lateral and vertical deviation from the ideal flight path and dispersal of the touchdown points were measured. Although the final results have not been published, suppose °the finding is that for three levels of texture, the lowest level shows significantly worse performance (on the measures described) than the two more detailed levels of texture, but that there is no difference in performance between the latter two. Although no significant differences in performance were found between the two greatest levels of texture, does this mean that no difference in training value exists or, alternatively, that is it possible that the measures were not sufficiently sensitive and that other measures should have been used?

An additional question in the context of the above example is what effects will the level of texture used during simulator training have on performance in the aircraft? Transfer of training studies between a simulator and the aircraft are expensive and time consuming. That it is important to do this kind of study has long been recognized but seldom carried out because of the considerable effort required. Without this information, how much reliance should a researcher, a visual system designer or a training officer place on the ground-based results? Will the amount of texturing in the training simulator have an important effect on time required to become proficient in the actual aircraft? Presuming there is an increase in cost associated with the greater detail of texturing, what decision should the designer of a new simulation system make about the required level of texture given this information? Also, should the system designer assume that the results of a single study are applicable to the system he is working when the purpose of his system may be quite different from that of the system on which the research was conducted?

The user of a research report can rely only on his own judgment until a number of similar studies in a wide variety of contexts result in a general principle. A single study, however well done, simply does not carry enough weight to significantly affect the design decision process.

Visual Perception Literature

Knowledge of vision and visual perception can be considered to be of two sorts: 1) knowledge about basic or elementary visual processes; and 2) knowledge about general or complex visual processes.

Knowledge about basic or elementary visual and perceptual processes includes understanding of the visual mechanisms, i.e. the optical and visual functions of the visual system; its reponse to simple stimuli, i.e. a disk of light of particular size, brightness and color; and accute targets such as letters or checkers of particular sizes and content. These sorts of stimuli are used to determine the fundamental characteristics of the human visual system such as contrast sensitivity, color discrimination, resolution ability, the effects of light levels, sensitivity to movement, size and shape discrimination, and the differences between central vision and peripheral vision. These fundamental visual characteristics are reasonably well understood in functional terms. That is, the response of the visual system to fairly simple types of stimuli under well controlled viewing conditions is predictable.

In the real world, however, the basic visual abilities are only a small, although fundamental, part of the total process of visual perception. Sometimes, the basic visual abilities are referred to as low-order processes. Abilities such as recognition, judgements of

distance and size, and interpretation of real or pictorial scenes are referred to as high-order processes. High-order visual abilities are complex. They depend on basic visual functions, but because of the large number of factors which affect real world perception, the contributions of basic functions in support of perception are obscure. They do not have much impact on the information gained through perception until, through gross degradation of the stimulus or viewing situation, the whole perceptual process is affected. For example, light level (brightness) has a predictable effect on acuity. A decrease in brightness, even by a small amount, results in a decrease in the ability to see detail. Under well-controlled task and viewing conditions the relationship between brightness and acuity can be described by simple mathematical formulas.

Acuity plays some part in the recognition of people, places and things. Recognition, however, is a complex process involving many factors such as memory, attention and the situational context. Recognition performance would not degrade importantly as function of brightness until brightness was reduced by a very large amount. The high levels of perception, those of most consequence in the real world, are very insensitive to these changes in the stimulus or viewing situation. However, such changes have a very obvious effect on the basic or low-level visual abilities. Many things intervene between the stimulus presented to the eye and the outcome of high-level perceptual processes.

The visual abilities of most consequence to simulator visual systems are the high-level ones. The pilot's performance will be most immediately affected by his ability to perceive his position, altitude and course; his recognition of ground features and targets; and the actions of his adversary. The perceptual processes which provide this sort of information to him are far removed from the basic visual processes.

The high-order perceptual processes are poorly understood (Uttal, 1979). Complex natural scenes defy quantitative description, and how the human visual system interprets these scenes is unknown. There simply are too many factors, both in the world and in the person, operating at the same time to be able to predict perceptual outcomes in real or simulated complex visual settings. The magnitude and complexity of the problem of understanding high-level perceptual process is probably one of the main reasons that they have received so little attention.

The characteristics of a simulated visual scene can be considered as being of two types: 1) image quality characteristics; and 2) scene content characteristics. Image quality characteristics are related low-level visual abilities, and scene content characteristics are related to high-level perceptual processes.

When experimental or analytic studies are undertaken to investigate simulator visual system requirements, the work is often limited to the image quality aspects of simulation (e.g., Kraft, Anderson and Elworth, 1979). Although the work performed is of high quality, the authors state very early that no consideration was given to issues of scene content. Visual system engineers will no doubt find their work very satisfying and easy to understand because the topics are generally limited to characteristics of the display, not to what should be displayed. The terminology of the authors and engineering readers is the same, and the research issues discussed are concrete and unambiguous.

Scene content must importantly affect the training value of a simulator visual system. The literature on high-level visual perception is of little help, however, in determining what are the important characteristics of scenes in terms of providing information to the pilot. Most of the literature on high level perception is descriptive or theoretical in nature. It is impossible to find, for example, an account of what characteristics of a scene are necessary to produce accurate perceptions of depth or size.

One the other hand, many books give lists of factors or cues which affect depth and size perception. These lists of cues, however, do not provide any substantial help in deciding what to provide in a simulated scene. Even the word "cue" has no commonly accepted definition. In the perception literature, visual cues refer to such things as size, interposition, motion parallax, binocular disparity, and the like. In the visual simulation literature the term visual cue has been applied to trees, lakes, texture, targets, aircraft attitude, and visual landing aids.

The knowledge of visual perception which is available to guide designers of simulator visual systems comes not from the general literature but from technical reports describing simulator visual system features and experiences with visual systems in training applications. Engineers, often with little guidance from visual experts, make common sense decisions about how a simulated scene should look. The record of successful use of visual systems to support flight training in simulators is testimony to their acumen. Most of what will be said about visual system requirements later in this section derives from past experience more than from the results of systematic research.

Trying to relate fundamental knowledge to a complex, real world activity has always been a problem for both engineers and psychologists working on applied problems in man-machine systems. University researchers have also become increasingly concerned about the lack of relevance of the knowledge gained from theoretical or "pure research" studies to everyday human activities. Recently there have been strong statements made that psychological research should be aimed at the larger issues of behavior as manifest in real world conditions, and should get away from the certain but limited-value studies typical of

most laboratory research (Gibson, 1966 and 1979; Neisser, 1976; Simon, 1979; Gibbs, 1979). It is not necessary to forsake all certainty or control to do more generally relevant research, but it does require thinking about major aspects of human behavior, such as visual perception, in broader terms, and the development of new research strategies.

In the mean time, efforts are being pursued by the Air Force to bring together in a systematic and useful fashion, the data which do exist in the vision literature. This work, named the Integrated Cuing Requirements Study, will attempt to interrelate the many isolated pieces of information about vision in a comprehensive structure which takes into account the multiplicity of interactions of basic visual characteristics and the consequences of these interactive effects on perception. The objective is to provide guidance to people concerned with the design and use of training simulators. While vision is emphasized, the study will include information about other perceptual systems as well, such as hearing and body orientation.

Visual Simulation Literature

The visual simulation literature can be regarded as falling into three general topic areas: 1) engineering descriptions which include advances in visual system technology and descriptions of simulator visual systems; 2) design requirements for simulator visual systems; 3) experimental studies of the effects of visual system characteristics on aircrew performance. Most of the literature is contained in technical reports issued by government laboratories or government contractors. A lesser amount is contained in published conference proceedings, scientific or engineering journals, and books. Most of the visual simulation literature was published in the period between 1963 and the present.

Overview of Visual System Developments. Before the early 60's there was very little interest or activity in simulator visual systems because, prior to that time, flight simulators were viewed mainly as useful for the training of non-visual tasks such as cockpit procedures, instrument flight and emergency procedures. Simulator technology is strongly linked to the evolution of computer technology. Rapid developments in computer technology have allowed the accurate simulation of aircraft flight characteristics and the ability to provide out-of-cockpit visual scenes. At the same time, escalating costs of military and civilian aircraft operations, due in part to fuel costs and shortages, were responsible for extending the use of simulation training for complex visual flight tasks such as air to air combat and air to ground weapons delivery.

The earliest interactive visual system was a point light source projection (Payne, et al, 1954). This was followed by development of film and camera model board systems. Because of their fixed flight

path, film systems had, and continued to have, very limited application. Until the 70's, camera model systems were limited to relatively narrow forward fields of view. Consequently, the primary use of these systems has been for training of takeoff and landing. Providing only a forward field of view satisfies most of the training requirements for commercial aviation training, but may be too restrictive for military flight training applications.

In the late 60's and early 70's, computer developments, particularly in graphics, promoted an interest in computer image generation (CIG) of synthetic visual scenes. The earliest applications of CIG were in night visual simulation. A night scene consists primarily of an array of points of light, and somewhat realistic looking night scenes could be created without overtaxing computational or display capabilities. Increased computational power and special computational equipment for CIG purposes soon led to the development of reasonably detailed synthetic twilight and daylight scenes.

Advances in display technology in the late 60's and early 70's also provided improvements in the realism of visual scenes. The first CIG daytime scene simulation system used for military flight training occurred in 1972 (O'Conner, et al., 1973). Better resolution and contrast, color, larger display formats and increased fields of view greatly enhanced the capabilities and realism of visual simulation. Improvements in display technology have also greatly enhanced the capabilities of camera model systems.

The expansion and increased use of visual simulation has promoted the division of visual system technology into several specialized areas of research and development. The specialties generally fall into the areas of image generation (in the case of CIG), image pickup (in the case of camera model systems), image transmission, and image display (projection and direct viewing). A few recent visual simulation systems are hybrid camera model and CIG systems. The trend toward CIG systems is clear, especially in ATDs used for continuation training.

Reports on visual simulation, however, do not offer much insight into how the characteristics of visual systems relate to training effectiveness. Generally, it is not their purpose to do so. Often, it is apparent that the authors of these reports also have struggled with the problem of trying to relate the knowledge in the literature on visual perception to physical requirements for a simulator visual system.

Engineering Descriptions. The first two categories of literature, visual system technology and descriptions of simulator visual systems, describe the development and performance of components of visual systems or the configuration and performance of the entire visual system. This literature basically presents what the equipment can do and how it is done technically. Performance specifications are generally in physical

terms, i.e., resolution; contrast; bandwidth; computational rates; linearity; distortion; total number of points, edges, surfaces, or solids that can be displayed; field of view provided; image update rate; achievable angular rates and accelerations; etc. The emphasis is always on the presenting of an image and image quality characteristics and not on what the image represents or how the pilot acquires information from the displayed scene.

Design Requirements. Reports in the second category of the literature, design requirements for simulator visual systems, usually contain a section entitled "review of the visual literature," "visual requirements," or the like. Generally, these sections cover a brief review of basic visual abilities such as acuity, contrast sensitivity, etc. Then, visual cue and scene composition requirements usually are discussed. A listing of the information and cue requirements for attitude, position and rate information is presented, followed by a description of the requirements for visibility of an airfield, target, other aircraft, etc., as applied to the training requirements. The relationship between the discussion of visual abilities and cue/scene requirements is never clear. This is predictable because of the general lack of knowledge about this relationship.

Having decided what the pilot needs to see, the equipment design specification follows. It is most evident from this category of literature just how serious is the lack of understanding about high level perceptual functions (e.g. Taylor, et al., 1969; Conant and Wetzel, 1970).

Experimental Literature. The information of most relevance to visual system requirements for flight simulators comes from the few experimental studies of effects of visual system characteristics on pilot performance and from the theoretical or review papers on pilot visual requirements and/or visual perception. Waag (1978) has published a recent review. Only four reports have been found which address the effects of systematic manipulation of scene content on pilot performance or training effectiveness (Payne, et al., 1954; Eisele, Williges and Roscoe, 1976; Lintern, 1978; and Randle, Roscoe and Petitt, 1980). The oldest study (Payne, et al., 1954) involved the assessment of the training benefits of the presence of a specific visual scene per se. Several studies deal with the effect of delays of motion in the visual scene following control inputs, and mismatching between motion base and visual scene movement. (See Chapter VI of this report) A few studies have been done on distance and depth perception in simulated scenes (Palmer and Petitt, 1976; Kraft, Anderson, and Elworth, 1977; Buckland, Monroe and Mehrer, 1977; Randle, Roscoe and Petitt, 1980).

A number of transfer of training (training effectiveness) experiments have been reported, although more are needed to clarify a number of visual system design and use questions. These studies and

related information gained through program site visits are presented in the first section of this chapter.

General Conclusions. Lack of directly relevant research is a key problem. The amount of work on visual scene content and cue requirements and their relation to training effectiveness is small. The reasons for this are fairly clear. First, sophisticated visual systems with which to do the research have been in existence for a relatively short time. Second, most simulators are constructed and used to fulfill urgent training needs, and little time is available for research. The Navy has recently procured a modern flight simulator, the Visual Technology Research Simulator (VTRS), solely for the purpose of engineering and behavioral research on visual simulation problems. The Air Force also has a visually equipped simulator specifically for training research: the Advanced Simulator for Pilot Training (ASPT).

Training simulators are not designed for the easy, systematic manipulation of variables, and have not often been used for research purposes. Training simulators are built for training, and any research conducted is usually a by-product. Once a training simulator and its visual system exist, there is little perceived value in determining whether a visual system with lesser, greater or different capabilities would be as effective or more effective for training purposes.

Assessment of Visual Simulation Validity. The validity of visual simulations, in terms of fidelity and realism, has been, and continues to be based on the judgment of pilots experienced in the aircraft being simulated. Rightly or wrongly and for a variety of reasons, pilots are extremely critical and skeptical of visual simulations which are not realistic. In the absence of alternative definitions of the goal or purpose of visual simulation, realism has been requested in procurements, and industry has devoted a large part of its research and development efforts toward providing greater realism. This is justified by the assumption that it provides greater training value. Unfortunately, there is no hard evidence to substantiate this common assumption (Caro, 1977; and Waag, 1978).

The pursuit of realism, implicitly or explicitly, dominates the visual system literature. The literature on visual simulation expresses concerns about what realism is and what is necessary to achieve it. Purely judgmental decisions are made about pilot information requirements for various flight tasks, which visual cues provide the information to the pilots, and how the presence or absence of particular visual cues affect pilot learning and performance (Conant and Wetzel, 1970). Common experience, such as pilot recommendations and designer judgments, have been the primary bases for justifying the content and image quality requirements for simulator visual systems.

Although subjective judgments may not be the best way to determine visual system requirements, there does not appear to be any substantial

alternative at present. Decisions must be made about how the visual system will be constructed, and the presumably applicable literature is simply too vague and non-objective to be of much help to the designer. Providing a hardware visual system that meets or exceeds the human visual sensitivities, and produces the greatest amount of potential detail in the widest field of view is about all that can be expected. Good, bad or indifferent, decisions are made and visual systems are produced, because they must be. But, the decisions do not evolve from a systematic body of knowledge derived from and confirmed by test and experiment.

Image Quality

Introduction. Topics addressed under image quality deal with visual system characteristics that have to do with the way an image is achieved, and factors which influence the appearance of the image, independent of the content of scene being displayed. The display system is a tool for presenting a picture. The characteristics of the display are considered to be enabling variables (Roscoe, 1979) which affect the light "signal" but do not directly have anything to do with the information that is provided by a visual scene. A discussion of scene content and the related topics of perceptual learning and augmentation follow this discussion.

Visual System Functional Components. A visual system can be regarded as consisting of five functional components with several fundamental options for each component. The five components of a visual system are: 1) image source; 2) image pick-up; 3) image transmission; 4) image display; and 5) image viewing. Figure 1 shows the principal options for each component and how they can be assembled to form different types of visual systems. Each of the topics discussed below deals with one or more of the functional components and/or the visual systems which result from a particular combination of the component options.

There is no question that display characteristics can have important consequences on the perception and performance of the pilot. It must be borne in mind, however, that because display characteristics are most closely related to the basic visual abilities, they are not as intimately related to behavioral consequences, i.e. flight performance, as are the high-level perceptual processes involved in getting and interpreting information.

Field of View Requirements. There is a general consensus that a wide field of view (FOV) is important for many military flying tasks and a relatively narrow forward field of view is limited in application to conventional aircraft takeoff and landing maneuvers (Harvey, 1978). Flight simulators, such as the Air Force Advanced Simulator for Pilot Training (ASPT), the Air Force Simulator for Air-to-Air Combat (SAAC), the Navy Visual Technology Research Simulator, and the Navy Air Combat

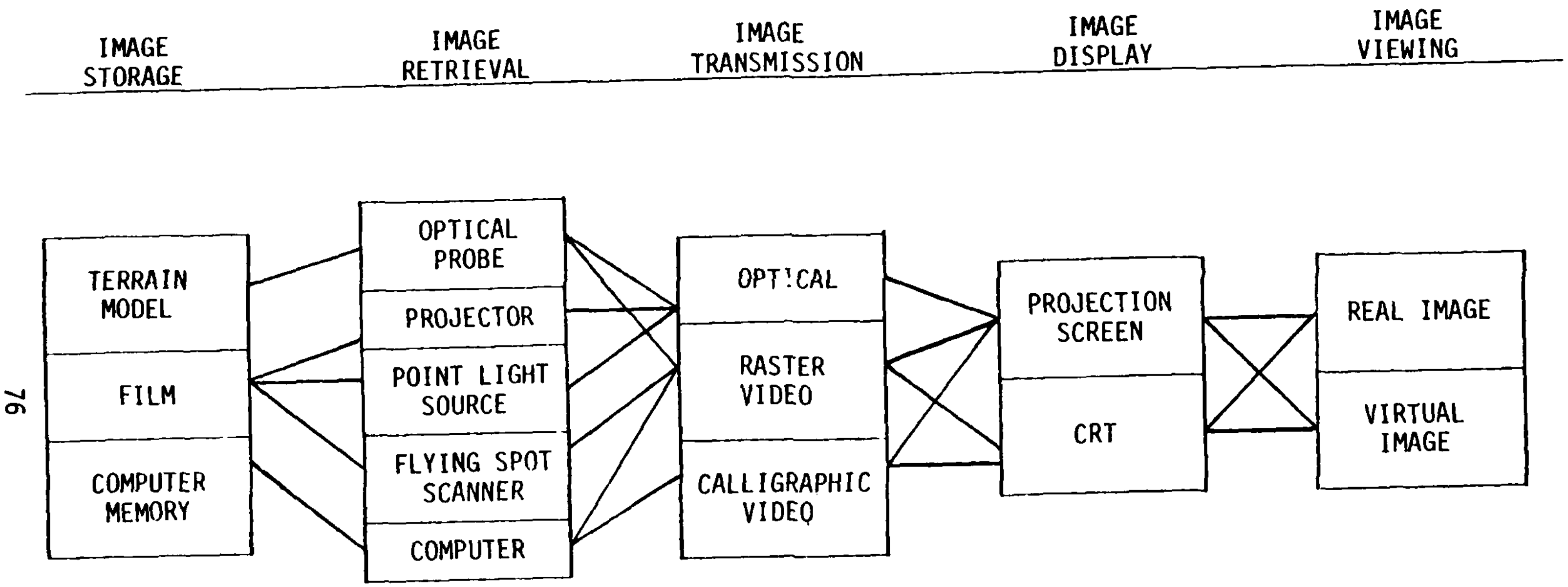

Figure 1. Block Diagram of Alternative Visual System Configurations

Maneuvering Simulator (ACMS, Device 2E6), have the capability of very large fields of view in excess of 160 degrees horizontally and 80 degrees vertically.

There is not much in the way of conceptualization or hypotheses of how differences in FOV might affect perception, and consequently performance and learning in a flight simulator. Recent visual research has supported the theoretical position that central and peripheral vision serve very different purposes (Held, Dichgans and Bauer, 1975; Leibowitz, Ginsburg and Post, 1979). The function of central vision is considered to be resolution of detail and pattern recognition. In other words, central vision tells one "what is out there." The function of peripheral vision is to detect objects entering the field of view and to provide information on "where they are out there." Also, peripheral vision is considered to be the primary channel for body orientation and locomotor information.

Locomotor information, in terms of the direction of travel and approximate rate of travel, is acquired through peripheral vision from the transformation of the entire field of view. Peripheral sensitivity to movement of the entire field of view, or optic array, is remarkable. Studies of circularvection, the illusory sensation of self motion resulting from movement of the entire visual field, have shown that this effect persists until scene brightness is reduced to near the bottom limit for detecting light, and is essentially independent of the natural error of peripheral focus of the eye (Leibowitz, Rodemer and Dichgans, 1979).

At very low light levels, when peripheral vision still functions adequately to provide orientation and locomotor information, central vision is nonfunctional. Maintenance of aircraft attitude and sensing of the direction and ground speed are functionally similar to perception of body orientation and pedestrian movements. On a very dark night a pilot, flying at low levels, could probably maintain attitude from peripheral vision, but could not see anything directly in front of him. This may not be of any practical significance for flying or simulator training, but it emphasizes that there are distinct functional differences between central and peripheral vision which are not simply a consequence of differences in psychophysical sensitivities such as acuity.

With these functional differences in mind, the question of FOV requirements should probably be regarded as two separate issues, i.e., FOV requirements to support central visual functions and FOV requirements to support peripheral visual functions.

In general, FOV requirements for central vision translate into requirements to be able to look out the forward and side windows of the aircraft. If a side view using central vision is necessary, it would be for tasks which demand that the pilot be able to recognize objects of

significance, resolve detail, detect small movements or make accurate judgments of lateral distance. For example, a side view would be necessary to detect other aircraft in the vicinity. It may be that use of central vision to the side is not necessary beyond the limits of what is conventionally considered a forward view display, i.e., 20 to 30 degrees to each side of center. Also, it may not be necessary to have complete continuity between the forward and side fields of view for central vision. A virtual window (area of interest--AOI) may be all that is required if there is a definite area or object where the pilot will (or should) direct his view.

A wide field of view for peripheral visual functions would be necessary if the tasks demand the ability to continuously detect altitude, attitude changes, direction of travel, changes in the direction of travel, approximate ground speed and the detection of objects which first enter the FOV from the side. It would be useful to know the effects of FOV size on sensitivities to, and control of, deviations in pitch, roll, yaw, direction and ground speed changes as a function of the pilot's central vision being primarily directed inside the cockpit versus outside the cockpit; scene content variables; and asymmetry of dislayed FOV (e.g. one forward display and one side display only).

Although FOV requirements are being researched (LeMaster and Longridge, 1978; NTEC, 1978), it is in a comparative fashion. That is, differences in performance of particular tasks are investigated as a function of display FOV. The possibility that there may be differences in FOV requirements for tasks or control functions that can be considered to be mediated either principally by central or principally by peripheral visual processes has not been considered. LeMaster and Longridge (1978) investigated the effects of FOV on an air-to-ground gunnery task using the ASPT. They concluded that no differences in performance were evident when the FOV was larger than 70 x 70 degrees. Milelli, et al, (1973) investigated the effects of 60, 120 and 180 degrees horizontal by 45 degrees vertical FOV on terrain following, terrain avoidance and precision hovering using a helicopter as the test vehicle. A simulated cockpit was constructed in the bay of a U.S. Army CH-53 helicopter. From inspection of the data they concluded that no performance effects could be discerned for the FOVs larger than 60 degrees horizontally. The inability to apply statistical tests to the data in the Milelli study may be partially responsible for the conclusion that no differences in performance were found as a function of FOV.

A recent series of two studies (Irish, et al, 1977; Irish and Buckland, 1978) tend to support the assumption that the effects of FOV size are different for flying behaviors mediated by central versus peripheral visual processes. The performance of experienced pilots was evaluated on five flight tasks as a function of FOV size, as well as other variables, in the ASPT. The five tasks were: takeoff; landing

approach; aileron roll; barrel roll; and a 360° overhead pattern. The FOV sizes investigated were 300° horizontal by 150° vertical; 144° horizontal by 36° vertical; and 48° horizontal by 36° vertical. The general finding was that the larger FOVs were associated with significantly better performance on all maneuvers except landing approach. The performance differences were primarily associated with roll and bank control and, to a much lesser extent, with pitch control. Only minor effects of FOV were found for the landing approach. The authors suggested that the FOV had minimal effects on landing approach performance because the relevant sources of information were located forward of the aircraft. Other studies (Roscoe, 1951; Reeder and Kolnick, 1964; Armstrong, 1970) have generally shown that performance on a landing task is minimally improved, if at all, when the FOV is larger than 50° horizontially.

Most of the information that is ordinarily considered to be picked up by peripheral vision can be detected by central vision as long as the pilot can look directly at the sources of information. The true value of peripheral vision probably becomes apparent when the pilot must use his central vision to read instruments or look at specific objects outside the cockpit. Peripheral vision will probably continue to acquire information independent of where the pilot directs his central vision.

Although a display device must have an FOV width and height to support task requirements for central and peripheral vision, it does not necessarily mean that what is displayed or how it is displayed need be the same over the entire FOV. Work on area of interest (AOI) displays has proceeded on the reasonable assumption that equal density of detail need not be present over the entire FOV. Work on AOI displays may produce even more useful results if it is recognized that peripheral and central vision have distinctive functional characteristics aside from the basic visual abilities of acuity, light sensitivity and color sensitivity.

The value of a wide FOV for training purposes is not necessarily reflected by performance on specific flying tasks. For example, scanning for other aircraft to avoid collisions is certainly an important, real world task. A narrow FOV visual system does not permit scanning behavior to be either learned or practiced. Also typical measures of performance reflect only control and procedural actions which have some effect on the aircraft. Activities such as scanning for other aircraft are not normally part of measuring performance, although it would be a good idea to do so considering its importance in actual flying.

Last, the value of a wide FOV may not have been apparent in the studies reviewed because the tasks did not specifically demand use of more than a central FOV. For example, air to air combat obviously requires a wide FOV. Therefore the decision on whether a wide or narrow

FOV is necessary for training purposes must take into account specific task requirements and not be based solely on possibly unwarranted generalizations from research results which are derived from a limited number of flying tasks.

Color Requirements. There is little question that a simulator display with color is very pleasing to pilots (Brown, 1975; Woodruff, 1979), but its utility for promoting training effectiveness remains unknown. Chase (1970) found small but positive advantages of color during evaluation of display systems used for training of approaches and landings. More recently, Woodruff (1979) found no differences in learning rates or final performance of a group of 32 Air Force undergraduate pilots on an approach and landing task as a function of using a black and white versus a color display. The display was a 44 x 28 degrees forward view TV type display system.

Display color can affect depth perception. There is a phenomenon known as the color stereo effect. Due to chromatic aberrations in the eye, objects of different colors may appear to be at different distances. Kraft (1979) is currently investigating the consequences of this effect on approach and landing performance as a function of the runway surround color. This experiment had not been completed at the time of writing this report.

Virtually all commercially available visual systems include a color capability. If a monochrome system were specifically required it would probably cost extra because it would be non-standard (Gurney, 1979). For a one-of-a-kind visual system, however, color may significantly affect cost. For example, the optics necessary to provide a collimated, virtual image (infinity) display which controls chromatic aberration effects and/or can selectively block or pass certain wavelengths is more complex than the optics for a monochrome display (LaRussa and Gill, 1978). A projected, real image (non-infinity) display that uses light valves and provides color would have to be more sophisticated than a black and white light valve system of equal resolution (Baron and Sprotbery, 1978).

Aside from enhancing the appearance of a display, color is considered useful in simulated scenes because it is an additional dimension for making objects and areas distinctive from one another (Ritchie and Shinn, 1973). In some cases, color may be the only means available for making certain objects distinctive. For example, in the real world, visual landing aids such as runway lighting, taxiway lighting and visual glideslope indicators, such as the Navy VASI, use color to make different patterns of light distinctive or as a code for glideslope information. When a night scene of a runway is presented in a simulator display it is usually thought necessary to display visual landing aids with the same color characteristics as their real world counterparts (NTEC, 1978; Woomer and Williams, 1978).

There may be options available, however, for presenting the same information that is now coded by color in a display scene. It is one thing to incorporate color in a display scene because its counterpart in the real world is colored, and another to use color because it is the only means of affording some necessary information. In the case of visual landing aids surrounding runways, it may not be necessary to use color at all if the same information can be provided by a different means, even if the information is not provided in the exact same way as in the real world. For example the glideslope information presented by a VASI installation could be provided by having the lights flash when the aircraft is above or below the glide path. In other words, some form of departure from a representational display may be equally workable; i.e., augmentation, in a sense, could be used to avoid the need to have a display system with color capability. It seems important, therefore, to investigate whether displays with color are necessary to represent visual landing aids and other lighting features in land based scenes, such as night displays of runways at established airfields and tactical airfields.

Color is regarded as a means for making objects and/or areas distinguishable and for coding information. Things also are distinguishable because of their brightness contrast, shape, size, texture and position. If what is necessary to be seen can be seen without the added dimension of color, then color is not necessary. For example, enhanced brightness contrast may be a useful substitute for color contrast. On the other hand, it may be more cost effective to use color instead of detail to make surfaces and texture elements distinguishable. Color may be a very effective means for affording symbolic information. For example, coloring an area, rather than altering its other characteristics, may be a means in reducing the required detail of a scene.

The possibility of the use of color as a substitute instead of a supplement to scene detail has not been considered before as an economic tradeoff question. Using alternative techniques for coding information in a display that is normally encoded by color in the real world has been done before, and color has been used to emphasize certain features of a display (Ritchie and Shinn, 1973). The possibilities of using both techniques, in the one case circumventing a requirement for color, and to highlight presumably important information sources in the other, should be experimentally investigated further.

Virtual and Real Image Displays. During flight in a real aircraft, everything the pilot sees outside of the aircraft is usually more than 20 meters distant. Even during takeoff and landing, the pilot does not normally see features of the runway at nearer distances due to windscreen restrictions on the lines of sight. Beyond six meters, the oculomotor adjustments of the eyes, i.e., accommodation and convergence, remain the same regardless of the distance of the objects being viewed. Anything located six meters or further from the eyes is considered to be

at optical infinity. Everything a pilot sees out of the cockpit can therefore be considered to be at optical infinity in terms of the effects on the oculomotor adjustments of the eye.

If a scene representing large distances is placed at a very near distance, such as at the plane of the windscreen, the pilot's convergence and accommodation will be affected and, in turn, his perceptions of size and distance will be affected (Roscoe et al., 1966; Leibowitz, et al., 1972). Further, if an external scene is displayed at a distance near to the pilot's eyes, any changes of the pilot's head position will have a significant effect on the line of sight to objects and places portrayed in the scene. Changes in line of sight angle that occur because of head movement are likely to affect distance perception (Gogel and Tietz, 1973).

Flight simulator visual systems have one of two types of display: a collimated, virtual image; or a projected, real image. The collimated, virtual image is achieved by optical elements placed between the pilot and a surface on which the image is formed. The optics cause the image on the screen to appear to be located at a distance usually in excess of 25 meters (Kraft, Anderson and Elworth, 1979). Projected, real image displays form the image of the scene on a screen. Typical distance of the screen from the pilot is 10 and 20 feet. The Navy Visual Technology Research Simulator and the Navy Air Combat Maneuvering Simulator (Device 2E6) use projected real images on screens located 10 and 20 feet respectively from the pilot's eyes. Both the collimated, virtual image displays and the projected, real image displays can provide a scene at a great enough distance, i.e. 10 or more feet, to avoid problems of size and distance perception which may be encountered if the scene were very near to the pilot's eyes.

Just because size and distance perception will be affected by having a scene at a near distance from the pilot's eyes does not mean that a near display is not usable for training purposes. Other features of the scene will still provide size and distance information. Mainly, these would be linear perspective and the perspective transformations which occur as a consequence of the dynamic character of this scene. It is very likely that the pilot can become perceptually calibrated to a scene displayed at a near distance, and his training may not be impeded either during ATD training or during subsequent inflight training.

In general, if a scene can be displayed at a distance of 10 feet or greater from the pilot, it is desirable to do so. If other considerations make it highly desirable or cost advantageous to present the scene at a nearer distance from to the pilot, it would probably have no serious consequences in terms of training effectiveness, except that a short period of time would be required for the pilot to adapt to the effects on size and distance perception that are likely to occur.

The choice of using either a collimated, virtual image display or a projected, real image display is a matter of practicality and economics. There appears to be no intrinsic training reason for choosing one type of display instead of the other. Further experimental research should be performed, however, to resolve this issue.

<u>Camera Model Systems and Computer Image Generation (CIG) Systems.</u> There are two principal methods for producing images for simulator visual systems: 1) a terrain model viewed by a moving optical probe connected to a television camera; and 2) images generated by computers using numerical data base models. Both types of systems currently are used for military and commercial aircrew training. Each type of system has advantages and disadvantages.

Camera model systems require the construction and maintenance of a terrain model. Energy (lighting and cooling) cost are high for these systems. Usually these models have a scale somewhere between 1:500 to 1:6000. The choice of scale depends on whether low or high altitude flying is being trained. Some camera model systems use a large scale model for a high altitude, cross country flying and a small scale model for takeoffs, approaches, and landings. The principal advantage of a camera model system is the amount of detail and realistic appearance that can be provided in the displayed scene.

Camera model systems also have several disadvantages: 1) The gaming area, the amount of terrain the model represents, is limited by the physical space available from a model of any given scale. The smaller the scale, the larger the model board must be to represent a fixed geographic area. 2) The achievable field of view, for a single video channel at high resolution, is basically limited by the band width of the image transmission system (Harvey, 1978). There are techniques which use a wide field optical probe coupled with several TV cameras and separate image transmission channels to overcome field of view restrictions (Mays and Holmes, 1978). 3) When a camera model is used for flight near the ground, the depth of field of the optical probe becomes an important consideration. A small entrance pupil is required to achieve a large depth of field. When the entrance pupil is restricted, however, the amount of illumination on the model board must be increased to provide an adequate level of light to the TV camera. The number of lights and the electrical power required for the lights and for cooling can be very large, and can be significant cost and energy considerations. 4) Having the optical probe follow the movement characteristics of the aircraft also is a major engineering and cost consideration in camera model systems. To produce the 6 degrees of motion of the aircraft at appropriate rates requires a very large mechanical structure. The size of the structure can affect the rates of motion possible and also the accuracy with which the probe can be positioned. 5) Camera model systems are relatively inflexible. That is, the gaming area represented cannot be changed without changing a significant portion of the terrrain model. 6) Special features which

may be desirable for some types of flight training cannot be achieved with a camera model system. For example, movement of ground objects, such as vehicles, is difficult to implement. Also, weapons effects, including missile tracks and ground strikes, cannot be simulated. Some sort of special purpose image generator is required to integrate the images of weapon effects into the camera model display. The principal problem with the use of such a special effect generator is accurately superimposing the images from the terrain model and the weapons effect generator (Cooles, 1979).

CIG displays have advantages and disadvantages that are almost the exact opposite of the camera model systems. Since all visual imagery is generated by a computer system, and a data base describes a terrain area, the following are computed: the size of the gaming area; how the features are represented; movement of ground and airborne objects; weapons effects; and scale. Changing or expanding the data base is a simple, but not trivial, endeavor. The field of view of CIG systems is limited principally by the computations required to maintain a particular density of detail over the FOV. To increase the FOV with the same density of detail requires additional hardware. Another way of increasing the FOV while maintaining a given density of detail is to add hardware for additional display channels. In CIG, FOV and displayed detail density are trade-off questions.

A CIG system is limited in its capacity for generating edges or surfaces. Two thousand edges is a typical edge limit for CIG imagery, although systems with an 8,000 edge capability have been built (Harvey, 1978). CIG systems with a 30,000 edge display capability have been promised (Swallow, Goodwin and Draudin, 1978). Whatever the edge capacity of the CIG system, the density of detail represented depends on the size of the FOV over which the edge capacity would be distributed. A large field of view can be achieved at the penalty of reducing the average number of edges per unit area.

The principal disadvantage of a CIG system is the density of detail that can be portrayed. Because of the restrictions on edge capacity, and the way that objects in areas in a scene are modeled, the resulting display has a cartoonish and unrealistic appearance. This lack of realism, however, is a disadvantage only if the premise is accepted that realism is an important quality necessary for aircrew training. The first section of this chapter cites many training effectiveness data which show the training value of highly cartoonish, black and white CIG systems. Presently, however, almost nothing is known about relationships between edge density and training effectiveness.

Resolution. Humans easily can detect that a scene does not provide resolution equal to the resolving power of their eyes. In the real world, however, obscuration and low light levels, such as occur during dusk and dawn, reduce the pilot's visual resolution ability significantly. Under these circumstances a pilot is still capable of

peforming his flight tasks, particularly takeoff and landings, even though his acuity may be considerably reduced. As with many other characteristics of visual simulation, there may be a large difference between the degree of resolution that is esthetically pleasing and that which is functionally important for training.

Resolution is the minimum angular separation that can be seen. Display resolution is typically quoted in terms of minutes of arc per line pair. In effect, one minute of arc visual resolution is equivalent to 2 minutes of arc per line pair resolution. The resolution limit of the human eye is nominally about one minute of arc. Both collimated virtual image displays and projected real image displays use raster scanning techniques to create an image. The resolution of these systems is limited vertically (assuming a horizontal raster) by the number of raster lines used. Typically, display systems have either 525 or 1,000 raster lines. Maximum horizontal resolution is typically 1000 points along a given raster line. A display scene can be considered to be made up of a two dimensional matrix of points. Each point is called a picture element or pixel. Resolution of a display is dependent on the horizontal and vertical distance between pixels, and the size of the light spot generated at each pixel. A display system may have a large number of pixels closely spaced but, because of their size, the pixel elements can overlap and, therefore, adjacent pixels may not be resolvable.

Resolution also depends on optical and electronic characteristics of the display system. In general, resolution near the center of a display is better than it is at the extreme edges. So, in practice, the theoretical resolution achievable by a display is almost never realized. Most simulator visual sytems, therefore, do not have a resolution value which is applicable over the full field of view. As a general statement, however, current simulator visual systems have a resolution range somewhere between 6 and 30 minutes of arc per line pair. The higher resolutions are usually achieved only with special, inset displays which have a variable size. Their maximum resolution at the smallest size is about 2 minutes of arc per line pair.

Achieving greater resolution is a technical question. Whether more resolution is needed for training purposes is a functional question. Milelli, et al., (1973) used a helicopter as a test vehicle for investigating the effects of display resolution and field of view on helicopter pilot performance. A simulated cockpit was installed in the bay of a U.S. Army CH-53 helicopter. The visual display consisted of three collimated, virtual image displays fed by three video cameras mounted on the nose of the aircraft. The investigation consisted of measuring performance on terrain avoidance, terrain following and precision hover as a function of resolution and field of view. Resolution was defined as presenting the displays with either 525 lines per frame or 1023 lines per frame. Three fields of view, 60, 120 and 180 degrees were used. The authors concluded, from inspection of the

data but without statistical analysis, that the 525 lines per frame resolution was sufficient for satisfactory accomplishment of all the maneuvers. Since the displays were 45 degrees vertically, the vertical resolution of the 525 line display was equivalent to approximately 10 minutes of arc per line pair.

Although no other reports that directly studied the effects of resolution on performance have been discovered, there are current plans for investigating this issue (NTEC, 1978).

From a functional viewpoint, it is difficult to say how resolution will affect either flight performance or flight training. An early study investigated the effects of display resolution, color and collimated versus projected imagery on landing performance of experienced pilots. The only effect of decreased resolution was an increase from 0.33 degree to 0.35 degree in glide slope error (Chase, 1970). A study by Fowler, et al., (1971) compared target detection for direct and indirect (via a 525 line television system) vision of a terrain board. Both viewing conditions were from a simulated moving aircraft. Unfortunately the authors did not state the size of the display or viewing distance from the display nor the resolution of the television system, so the resolution of the system is unknown. The findings were that the targets consisting of tanks, trucks and buildings had to subtend 2.5 and 4.5 minutes of arc, visually, to be detected and recognized, respectively, by direct vision. For viewing by television, the targets had to subtend 7 and 15 minutes of arc, visually, to be detected and recognized respectively.

A reasonable question is, assuming a visual system with 10 minutes of arc per line pair resolution, what features of importance would be available with finer resolution? Another way of stating the question is to ask what fine detail contributes to the pilot's ability to perform his task. Fine detail probably would aid in the earlier recognition of significant objects and areas, and may contribute to using texture information for distance and ground contour perception. Whether these factors significantly affect performance or training effectiveness presently is unknown and requires further experimentation.

CIG Edges. The detail that can be displayed by a CIG visual system is principally limited by the processing speed of hardware that generates the image. The rate at which new images can be generated (i.e. updated) is determined by the TV frame rate. Consequently, the amount of detail that can be displayed is a function of how much processing can be done between each update of the image. Advances in the design of image generation hardware and processing algorithms continue to increase the amount of detail that can be displayed by a CIG system.

The amount of detail in a scene that can be produced at the required image update rate by a CIG system is usually stated in terms of the

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number of primitive elements that can be processed. The nature of the primitive element is dependent on the design of the visual system hardware. Usually, an edge is defined as the primitive element although points or geometric solids have been named as primitive elements.

The number of edges which can be displayed has increased more or less continuously since CIG was first used for flight simulators. The first interactive flight simulator visual system, which was not a CIG system, consisted of 5 lines: a runway outline and a horizon line. It was demonstrated by a transfer of training study to be highly effective for novice pilot training of landing skills (Payne, et al., 1954). The first CIG system, which portrayed solid objects in a scanned display, was used by NASA in 1962, and had a capacity of 240 edges (Bunker, 1978). The first CIG system used in a military aircraft training simulator was attached to Device 2F90 and had a 500 edge capacity (O'Conner, et al., 1973). A report of the detailed design requirements for a universal flight simulator (Conant and Wetzel, 1970), which was never built, discussed the question of the number of edges that would be required for the CIG visual system. The choices were narrowed down to either 576 or 874 edges. Based on instructor pilot expert opinion, it was finally decided that 874 edges would be required. The U. S. Air Force ASPT has a 2,000-2,500 edge capacity (Gum and Albery, 1976). A C-130 flight simulator which is projected to be operational in 1980, will have a edge capacity of 8,000 edges (Harvey, 1978). Visual systems with a capacity of 30,000 edges are being developed (Swallow, et al., 1978).

The number of edges required, i.e., the required detail of the displayed image, is a complex question for which there is no answer, either simple or complex. Scene detail presumably reflects the ability of the display to provide information to the pilot. More detail does not necessarily mean, however, that more information is acquired by the pilot. It has often been said that the principal determinant of the value of a simulator is how the equipment is used for training and not the physical characteristics of the equipment. The same is true for scene detail. How the edges are used to model a scene to achieve the desired perceptual effects, and consequent performance and training effects, is a more important consideration than how many edges are available to do it with. Increasing the number of edges that can be used simply increases the likelihood that critical features of a display, if there are such things, will be adequately represented. In general, increasing the number of edges in a display increases the apparent realism of the display. Whether this is desirable is an open question (Bunker, 1978).

Increased scene detail may or may not be beneficial for training depending on how it is used. For example, Le Master and Longridge (1978) found that increased detail, which they described as "enhanced texturing" of the ground plane, did not aid in air-to-ground target acquisition in the ASPT. As might be expected, the pilots who

participated in the study reported that target acquisition was more difficult with the greater amounts of ground plane texturing. If the training purpose includes the need to acquire targets which are difficult to find, as would often be the case in the real world, then the increased ground plane detail helps to achieve this purpose. If, however, the training purpose is to train the procedures of attacking the target, making the target difficult to acquire in the first place by increasing ground plane detail may make the attack training less effective. Targets may be missed or acquired too late to execute the proper attack procedures. So, in this case, whether the increased ground plane detail is considered beneficial or detrimental to training effectiveness depends on what specific training objectives are involved.

There is no empirical evidence for deciding what minimum amount of detail is required for training different flight tasks. Simple flight tasks, such as takeoff and landing of conventional aircraft, probably do not require as much detail in the visual scene as do more complex or difficult tasks such as low level navigation and air-to-ground weapon delivery.

Research plans have been formulated, however, to study the effects of scene detail on performance and training (e.g., NTEC, 1978). Until studies on the effects of scene detail and content are performed, requirements for the number of edges in a CIG display will remain an open question.

Display Channels Required. A single channel visual system has only one image source, image pick-up, image transmission system and image display. More than one channel can be used to provide additional display capability. When multiple channels are used the channels split either at the image source or image pick-up, and always have separate image transmission and image display components. Multiple channels can be used in three ways to display: 1) adjacent terrain areas, i.e., increased FOV; 2) the same terrain area from a different viewpoint; or 3) a separate area of interest inset in, or superimposed over, a background display.

For all these applications the number of channels required depends on considerations of the visual system design, such as the width of the field of view required, the amount of detail in the field of view, and the fundamental equipment approach to accomplish this. For example, using different channels to provide surround information and area or object of interest information permits the surround information to originate by one means, (e.g., CIG) and the area or target information to originate by another means (e.g., camera model). The U.S. Navy VTRS uses display channels in this way (Booker, 1977).

The use of different channels to provide views of the same area from a different viewpoint is found primarily in collimated virtual image displays where the pilot and co-pilot are seated side by side in the

cockpit. Without separate displays for each crew member it is impossible to provide a correct perspective view to each of them. With separate forward area channels for each, the correct perspective view is provided. Side views, however, which may be viewable by both crew members, can only provide a correct viewpoint for one of the aircrew members.

Whether the incorrect perspective view that would result if one crewmember views a display intended for another will have a significant impact on performance or training is unknown. If both crew members are being trained simultaneously, and both are involved in the performance of tasks which depend on an extenal view, then it is probably desirable to provide separate channels for each crew member, particularly for tasks such as landing where correct perspective may be considered an important element for performance. However, experimentation is needed to clarify this issue.

CIG System Update Delays. A CIG image requires updating because of changes in attitude or position of the aircraft. When the pilot makes a flight control input, the simulator control computer must calculate the response of the aircraft to the control movement. Once the aircraft response is calculated, this information is passed to the image control computer which then produces an appropriately updated image corresponding to change in the eyepoint as the aircraft moves along. Computation of the aircraft response and the new image can take an appreciable amount of time. Consequently, there often is a delay between when a control is moved and the effects are seen in the displayed image.

In current CIG systems, a total delay between a pilot's control input and response by the visual system ranges from approximately 100 to 200 milliseconds (Ricard et al., 1976). These delays can result in the pilot overcontrolling the aircraft and the impression that the aircraft is unstable.

The undesirable effects of display update delays can be overcome by using a predictor algorithm to determine what the appropriate image should be at the time it is actually displayed, rather than simply displaying an image that may be 200 milliseconds (.2 + second) late. Predictor algorithms, however, are influenced by the frequency of aircraft responses. For low frequency aircraft responses, the predicted image does not change much from one update to another. But high frequency components of the aircraft response produce values affecting the predictor algorithm that can fluctuate considerably from one image update to another. The consequence of the inclusion of high frequency values in the prediction algorithm is that the display will appear to jitter.

The principal method of preventing the bad effects of high frequency components on the image prediction algorithm is to filter out the higher frequencies of the aircraft responses so that they do not affect the

displayed image. The cut-off frequency, i.e., the lowest frequency that is allowed to affect the predictor algorithm, must be carefully chosen and must be tested in the ATD.

If the cut-off frequency is too low, the display will appear non-responsive to the pilot. On the other hand, as has just been described, if the cut-off frequency is too high, the scene will appear to jitter because of errors in the image prediction equation. The results of a study (Ricard, et al., 1978) of formation flying performance, which was done on the ASPT, indicated that a cut-off frequency of about 1 Hertz (1 cycle per second) produces the best combination of performance in terms of average pitch and roll errors and judged acceptability of the display by the pilots. In other words, a display predictor algorithm which does not respond to aircraft movements at frequencies greater than 1 Hertz is probably desirable for many visual flight tasks requiring fine control.

Ricard and Puig (1977) reviewed available research findings and, combined with their considerable knowledge of the effects of image delays, concluded that image delays should not exceed 83 to 125 milliseconds, although longer delays may be acceptable for certain flying training tasks. They present data in their report which show that acceptability ratings of a display are high if the delays are 175 milliseconds or less. Delays beyond 175 milliseconds result in a constant decrease in display acceptability ratings with increased delay time. Riley and Miller (1978) performed an altitude tracking (following a lead aircraft) experiment, using two pilots as subjects, and varied image delay time. A fighter type aircraft was simulated and pitch control was emphasized. They concluded that, for their task, delays up to 250 milliseconds were possible before altitude tracking performance deteriorated. This delay, however, seems a bit large.

For airlines to receive approval to use ATDs to satisfy landing training requirements, CIG visual systems will be required to meet a set of FAA requirements for acceptable image delays. The maximum allowable image delay will be 150 milliseconds. This value may be subject to modification in the future. (See Chapter VII of this report for additional discussion of this topic.)

Image Improvement

Introduction. Image improvement topics generally relate to the abnormal characteristics of visual simulation which are consequences of how a visual scene is generated and displayed (i.e., image quality) as opposed to what the scene contains(i.e., what is represented). A comprehensive analysis of image quality factors which may influence the effectiveness of visual similation for flight training has recently been completed by Kraft, Anderson, and Elworth (1979). Their tasks were: 1) define the design characteristics which may affect perceptual or physiological responses; 2) establish the relative importance of the

corresponding visual and physiological effects; 3) understand the relationship with the physical continuums of the displays; 4) determine those areas for which insufficient definitive data is available; and 5) develop experimental designs for possible research. The following is a summary of their findings.

Topics considered to be of particular relevance included the following: 1) simulation system characteristics which degrade the realism of the displayed imagery and impart cues of "simulation" rather than "reality" to the crew; 2) characteristics which provide artificial or false visual cues, but which are needed to accomplish a simulator specific performance task; and 3) characteristics which may produce physiological or visual-physiological reactions, such as fatigue, eyestrain or motion sickness. Characteristics of simulator displays which were not addressed include scene content requirements and stereoscopic systems. Also, an important restriction was that the effects of the characteristics on simulator training effectiveness were not considered by Kraft, et al. The reader should bear in mind that the issues of image quality discussed below may or may not have consequences for training effectiveness.

A large number of topics related to image quality were identified. To keep the effort to a reasonable scope, Kraft et al. ranked the issues in order of importance, and only topics considered to be of major importance were treated further. The factors used for ranking the image quality topics, in descending order of importance, were: 1) false cues, i.e., the potential of the characteristic to produce a false visual cue; 2) interaction of characteristics, i.e., the potential for interaction of a characteristic with other visual or system factors to produce adverse effects; 3) current prevalence, i.e., the prevalence of the characteristic in current visual simulation systems; 4) realism deficiency, i.e., the extent to which the characteristic degrades the realism of the displayed visual scene; and 5) correction cost, i.e., the potential impact of the characteristic, if its effect is to be eliminated or minimized, upon the design, construction and cost of operation and maintenance of the visual system.

Forty-one potential image quality topics were originally identified. After ranking their importance according to the above criteria, combining some of the topics, and discussions with Air Force technical representatives, nine topics were selected for detailed attention. These nine topics are:

Aliasing;

Magnification;

Scene overlays and inserts;

Binocular deviation/binocular image size differences/divergence;

Lateral divergence/image distance and variability/collimation/image distance error;

Scene misalignment;

Visual system lag/update;

Color differences; and

Temporal intensity fluctuations.

Only the first six topics were treated in depth.

Their literature search uncovered about 550 reports which had a bearing on one or more of the topics. Only the literature dealing with experimental results which met criteria for soundness of design were considered and discussed under the relevant topics. A brief synopsis of each of the six topics discussed by Kraft, Anderson and Elworth is given here. In most cases, it will not be possible to draw a conclusion or make a recommendation to aid in determining the functional requirements for a simulator visual system, because the topics were specifically selected to be those most deserving of research attention. The intent of the following summary descriptions is primarily to make the reader aware of the issues.

Aliasing. Aliasing is a term used by engineers to cover a multitude of visual effects considered as display anomalies which are due to quantizing and sampling at various stages during the generation, processing and display of television images. The resolution of the eye exceeds the resolution of the visual system. Consequently, when continuous lines, distinct points, or what would be a smooth transformation of a point or a line in a scene is actually displayed, a lack of spatial or temporal continuity is noticeable. For example, a very thin line that is drawn at a small angle across several raster lines in a scanned display would appear as jagged line segments (like stair steps) because of the gaps between raster lines. A point of light that initially appears on one raster line of a display may, because of aircraft movement, subsequently appear on an adjacent line. Visually, the point of light may appear to jump from one line to another.

Some of the words that have been used to describe aliasing effects are shearing, tearing, flickering, creeping, sparkling, streaking, bouncing, oscillating, racing, jumping, skipping, edge walking, and reversing. A number of factors influence just how visually apparent aliasing effects are. Improvements in resolution and update rate of

displays would do away with many aliasing problems (Kraft, Anderson and Elworth, 1979).

Magnification. Displays are sometimes magnified to have a scene fill a specified display area or because pilots have complained that things represented in the scene are "too small" (Roscoe, et al., 1966). The same pilot responses occur today.

There are three types of magnification that can be applied to a simulator visual system. Optical magnification is a uniform expansion of the size of the displayed area relative to the area being represented. The perceptual effect of optical magnification is a "flattening" of the perceived depth in the scene. It is similar to the effects that occur when a telephoto lens is used to produce an image. A second type of magnification is size magnification that involves a uniform increase in the visual angle subtended by depicted objects. As in optical magnification, the perceptual consequences are related to perceived size and distance relationships, and are highly dependent on the context of the specific viewing conditions. A third type of magnification is distortion or non-uniform magnification of different portions of the scene. Typically, this type of magnification results from barrel or pincushion distortions in the display.

The effects of these types of magnifications on pilot performance and/or training are either unknown or unclear. An overall increase in magnification of a scene, because of complaints that everything looks too small, may have more benefits than drawbacks (O'Conner, et al., 1973). Since magnification can be accomplished after a simulator visual system is built and put to use, it is worth bearing in mind that if problems or complaints of size perception are encountered, it would be possible to increase the magnification to determine if this solves more problems than it introduces. The ease or difficulty of changing magnification will depend on the type of visual system used.

Scene Overlays and Inserts. Overlaying is simply superimposing one image on top of the other in a display. For example, in Device 2E6, the Navy Air Combat Maneuvering Simulator, a sky-earth background is achieved by projecting the image of a transparency using a point light source. Images of other aircraft, produced by separate projectors, are simply superimposed over the background image. Because the target images are much brighter than the background, the background cannot be seen through the aircraft images. Overlay projection, either by superimposition of real images on a screen or combining images from separate sources through a beam splitter, can be a very effective display technique, if the superimposed image is much brighter than the background image. If it is not, and the background can be seen through the superimposed image, it will have a ghost-like quality or the detail of the superimposed image will be washed out. Overlaying also may make a target more visible than it would be in the real world. A target darker than the background, i.e., having negative contrast, which

often occurs in the real world, cannot be achieved by overlay techniques.

Insetting is combining one image with another, but with the background image masked out either physically or electronically. Insetting is a commonly used technique with Area of Interest (AOI) displays. Problems with insetting are associated with discontinuities at the edges of the inset display. The most promising method for avoiding discontinuities at the edge of the inset image is to assure that the background and inset image contrast match or blend at the edges.

Binocular Deviations and Image Size Differences. Monocular displays, in which both eyes see the same image, are predominantly used in flight simulators. Because each eye has a slightly different viewpoint when viewing the same image, there may be distortion effects which alter the image size in each eye. In general, disparities in the size or alignment of images between the two eyes in the vertical direction are worse visually than disparities or misalignments in the horizontal direction. Mismatches in the images seen by each eye may produce eye-strain or related fatigue effects. In general, however, current visual systems present images to the two eyes that are sufficiently well matched to avoid these problems.

Lateral Vergence/Collimation/Image Distance Error. If the convergence of the eyes required by a display is different from the accommodation (focusing) requirements, eye-strain and fatigue effects, and visual performance effects, may be encountered. Although the convergence requirements and the accommodation requirements for some displays, particularly collimated virtual image displays, are not perfectly matched throughout the image, they are usually sufficiently well matched that adverse effects are highly unlikely.

Scene Misalignment. When multiple, collimated, virtual image CRT displays are used to extend the field of view of the external scene, there may be discontinuities in the images at the edges of the displays. These discontinuities may be very evident when the display screens are butted very close together. Proper matching or maintenance of continuity across displays is not simply a matter of physical alignment of the screens. Small differences in the gain of each display and distortions near the edges of the display, which may be unique for each display screen, can make it difficult to get good continuity. Research to determine the threshold for the detection of discontinuity as a function of rotation, separation and elongation of the displays has been proposed by Kraft, Anderson, and Elworth. Presently, there are no data on which to base scene continuity requirements.

Scene Content

Scene content is probably the most elusive issue in visual simulation. There is no adequate terminology for describing the appearance of a scene nor any agreement about what are the relevant characteristics of a scene (Thorpe, 1978).

Early visual systems with modest capabilities, i.e., the display of fairly simple scenes, have been shown to support effective training for basic flight tasks typically taught during initial stages of flight training. Advances in visual system technology have led to the present ability to produce fairly detailed, reasonably realistic looking scenes. These advanced visual display capabilities may be necessary to extend the use of ATD's for training complex and demanding flight tasks beyond basic flying skills. For example, learning of mission skills such as low level navigation and ground attack against a reactive target are likely to require more complex and realistic simulated scenes than are necessary for more fundamental tasks. Complex scenes may also be necessary for maintenance of proficiency training for highly experienced pilots. The problem is that there is no way of predicting what characteristics of a scene, in terms of detail, features represented and realism, promote training effectiveness.

The following is a discussion of the features of scene content and how they seem to relate to visually acquiring information to perform flight tasks. Since virtually nothing is known about scene content requirements, this discussion is largely opnion. The purpose of the discussion is to point out what are considered to be the important issues of scene content that deserve research attention.

Perception and Scene Content. Gibson (1966 and 1979) makes an argument that there are invariant characteristics in the optic array (the light that carries information about the environment) which do not depend on seeing particular things in the world or seeing the world from a particular viewpoint. No matter what is seen from where, a stable perception of the world emerges. The world appears to have continuity and depth, objects and places retain constant identities, and the viewer is aware of where he is with respect to the world. Images produced in the eyes change constantly, but the perception of the way the world is remains invariant.

The exact nature of a source of information is considered to be important only to the extent that it allows and facilitates necessary and correct perception. There can be many sufficient sources of information, no one of which is necessary by itself. Displayed scenes that are very different in appearance can afford the same information. There are informational constancies which are perceived regardless of appearance. Things in the scene are sources of information, but are not the information itself. Determining what are the informational invariants

would be extremely useful. Making these determinations will require both creative thought and research.

One of the most important perceptual considerations for scene content is the consequence of providing a dynamic scene. It appears that the natural inclination for seeing in depth is an inherent characteristic of the visual system. Gibson (1966 and 1979) asserts that seeing in three dimensional space is fundamental. The third dimension does not arise perceptually from the synthesis of two dimensional information; seeing in depth is an inherent characteristic of visual perception which always occurs in the absence of contrary information, i.e., that a scene is flat. Gibson's assertion is substantially supported by the work of Johansson (1975). Seeing in depth is a direct consequence of the perspective transformations that occur due to motion of the observer or the objects that are seen. Johansson has called attention to the very important point that movement of viewers and objects in the world is the usual and normal state of affairs. The lack of motion, i.e., absence of transformations of the optic array, is a very special and unusual case. He has shown that when a display consisting of points or lines of light move in a variety of regular fashions, a viewer always perceives a rigid object moving in depth. That is, the viewer never sees independent movement of the elements but sees them as part of a larger structure undergoing perspective transformations.

Since visual scenes in flight simulators are always dynamic, the scene will always be perceived three dimensionally in the absence of contrary information. The implication is that producing depth per se is not a consideration as long as the scene changes according to the laws of perspective, and cues suggesting a flat display are minimized.

Information sources should be spatially redundant. It is not necessary that sources for all types of information be visible at all times as they might be in a natural scene, but sources for some types of information should be visible most of the time. Specifically, it seems necessary to provide sources for attitude and positional information all of the time. Objects and places need to be distinguishable most of the time and need to be recognizable only if they have particular significance, e.g., being the target, the place the aircraft will land, or a landmark for navigating a particular course.

Texture. The view from an aircraft of the natural ground always contains areas which vary in form and size. Every surface of the ground plane is made up of something and, in turn, it may be part of a larger feature. When the elements of an area are of no consequence as individual entities, they are said to be textural elements. Texture defines a surface and gives it a solid appearance. Textureless surfaces occur only rarely in the real world. The concern here is not with the exceptional conditions, but the usual ones. Therefore, a scene of a ground plane should afford the appearance of texture so that surfaces

appear continuous and solid. The topics of scene content just discussed are summarized by the following general statements: 1) The scene should obey the laws of perspective transformation; 2) A groundscape or seascape should contain spatially redundant sources of information, i.e., extend across the potential field of view; and 3) Surfaces should be textured to appear continuous and solid.

A scene which meets the above requirements will provide sources for almost all the pilot's information requirements. Attitude and positional information can be acquired as well as information for altitude, direction of travel and ground speed. These very few characteristics of the scene afford a great deal of information to the pilot. To afford all the information the pilot requires, it is necessary only to add features which allow particular places, objects and events to be recognized.

Display of Objects. The need to represent familiar objects in a scene is easily justified. The presence and arrangement of familiar objects can establish a unique location on the ground. Familiar objects, therefore, afford information for orientation with respect to the ground. Familiar objects also can have special significance. Obvious examples of significant, familiar objects are runways, targets and other aircraft. In addition to establishing the identity of places and being objects of inherent significance, familiar objects probably are important sources of information for the perception of distance and altitude. Trees, for example, have a known size of between a few feet to perhaps 200 feet in height. Roads and railroad tracks have a familiar width.

At very high altitudes, man-made objects and vegetation features become insignificant indicators of altitude and distance, other than indicating the aircraft is very high above or very distant from these objects. At high altitudes, very large objects, such as mountains or areas of vegetation, have more significance for estimating of altitude and distance. At high altitudes, however, being able to visually determine altitude and distance accurately just through the visual scene is not very important. Near the ground, knowledge of altitude and distance is very important. The number and spacing of familiar sized objects can be seen, and the range of sizes of these objects must have some influence on the perception of altitude and distance. Assuming that objects are located on a textured plane and the texture itself is not of familiar size, then it is probably necessary that at least one object of familiar size be in the pilot's field of view. It is an open, but important question of how many familiar objects over what range of size are necessary to allow a pilot to navigate and to judge distance and altitude with the accuracy required.

Object Detail. The amount of detail that is necessary to portray an object is an important question. It is probably necessary only to provide sufficient detail to allow the object of interest to be

recognized and possibly to be identified as different from similar objects. In some cases, detail may be necessary to provide a source of information about the orientation of an object, particularly vehicles.

What characteristics of an object are necessary to make it recognizable cannot be defined based on present knowledge. An object can be represented symbolically or pictorially. If it is pictorially represented, the range of potential detail of representation is obviously great. Portrayal of some objects symbolically rather than pictorially could probably be done in many instances when it is necessary for the pilot only to know what the object is and where it is.

Use of symbolic representation may result in a savings of display resources. It may also be used instructionally to emphasize the need to concentrate on objects as sources of information which are pictorially represented, and de-emphasize objects which are symbolically represented. If symbolic representation conserves display resources, it probably does so at the price of not providing familiar size information, which may be useful for judgment of distance and altitude. If an object is pictorially represented, there probably is no benefit in depicting the object with detail greater than is necessary for the object to be recognized. On the other hand, if the representation is very abstract and lacking in detail, it may not provide information on size and distance as readily and accurately.

Arrangements of Scene Elements. Another potentially important characteristic of simulated scenes is the repetitiveness or randomness of both the representations and arrangements of objects in a scene. Should all identical objects appear identical in shape and size? If not, and one of a number of the same objects has particular significance, what criteria should be used to determine the arrangement in a scene? For example, assume a pilot has the task of maneuvering an aircraft through an approach and landing to a runway surrounded by trees. Does it matter if the trees all have the same size and shape and are arranged in a regular pattern? Perhaps the regularity would enhance the pilot's ability to notice deviations in approach path or attitude changes near the ground. On the other hand, a random variation of placement of the trees may aid the pilot in acquiring positional information near the end of the approach. Further experimentation is needed to resolve these and related issues.

Concluding Comment. The foregoing discussion gives some idea of what should be the principal requirement for a simulated scene - the most convenient and economical way to portray a scene to the pilot that affords the required information necessary for effective training. Presently, there is no rigorously systematic way of specifying or manipulating scene content variables. In developing exact scenes for training, a leap must be made across the gap of knowledge between what information is required by a pilot to perform his tasks, and the appearance of the scene. It is hoped that the foregoing discussion of

scene content variables at least gives some indication of which directions to consider in the future.

Perceptual Learning

Introduction. During flight training, a great deal of emphasis is placed on acquiring the perceptual-motor skills necessary to control the aircraft, and on flight procedures for executing particular types of maneuvers such as takeoff, approaches to landing, landing, and various maneuvers for navigational and mission purposes. How the pilot is able to acquire necessary visual information in terms of noticing important relationships, being able to make accurate discriminations, and look at the right things, is unknown. Pilots must learn to extract information from a visual scene, and they do. Because perceptual learning occurs together with learning to control and maneuver the aircraft, and because so little is known about perceptual learning, are probably the reasons why so little formal instructional effort is devoted to the perceptual side of perceptual-motor learning.

Acquiring Information. Providing sources of information is no guarantee that the information will be acquired. It is a virtual certainty that when a pilot first learns to fly an airplane he does not acquire all the information necessary; eventually he learns to do so. Initially, even the best display, the real world, cannot infuse the pilot with all the information he needs. The pilot must learn where to look in the outside scene, what to look for, and to make the necessary discriminations. The same type of learning must occur when a pilot learns to fly by visual reference in a simulator. Information sources can be presented, but the pilot must learn to use them.

Perceptual Learning in The Real World and ATDs. An experienced pilot learns to fly at night and in other conditions of marginal visibility where much less can be seen than on a clear, bright day. Regardless of differences in the terrain or the conditions of visibility, if visual flight is possible at all, an experienced pilot can acquire the information necessary to fly safely and effectively. Thus, the pilot's perceptual abilities are remarkably adaptive. The pilot learns to operate in a variety of visual environments, and makes the correct responses in spite of great differences in the visual scene.

The differences between a simulated scene and a real world scene do not necessarily have any greater perceptual and behavioral consequences than the differences between two real world scenes themselves. Pilots learn to extract the necessary information from real world scenes which differ greatly in appearance.

It is well known that perceptual problems often occur when an experienced pilot flies a simulator (Ritchie and Shinn, 1973; Stark and Wilson, 1973; NAS NRC-Vision Committee, 1976; and Kraft, 1979). These problems, evident from performance, are often verbalized as the

inability to get certain cues, being distracted by anomalies in the display, or misperception of altitude and distance. Often overlooked or dismissed is the fact that in a relatively short amount of time pilots are able to adjust to the simulator's visual characteristics and perform well. It appears that perceptually adjusting to the simulator environment is not simply a matter of consciously overcoming evident differences between perception of the pictorial display and the real world, but actual perceptual learning occurs, i.e., the pilot becomes perceptually calibrated to the visual display.

Stark and Wilson (1973) reported that during an evaluation of the Air Force Simulator for Air to Air Combat (SAAC) the pilots initially complained that the distant terrain, made up of .5 mile squares laid out in a checkerboard pattern, appeared to move more rapidly than appropriate. The authors wrote: "Interestingly, during the evaluation the pilots were able to compensate for this effect, and as the evaluation progressed it became less of a problem." A little later it was stated: "Perception of altitude and altitude rate was difficult for all of the pilots until they had become calibrated to the appearance of the checkerboard squares." These statements indicate that the pilots did adjust to characteristics of the simulated scene which are not encountered in the real world. It is very likely that the ability to adapt to an unfamiliar visual scene through perceptual learning can also result in the ignoring of extraneous or undesirable features such as alaising or distortions, which may be overcome technically only at great costs.

The appearance of a scene in an ATD may be somewhat different than the appearance of the world when flying a real aircraft. This does not mean that a pilot will misperceive or that his performance will be adversely affected when he does fly the real aircraft. Simulated visual scenes need not appear highly similar to the real world to be effective for training perceptual-motor abilities which have high positive transfer to the aircraft.

Taking Account of Perceptual Learning. The ability of a pilot to undergo perceptual learning, both in the simulator and in the real world, suggests that it should be possible to realize benefits in terms of rate of learning and cost savings in ATD's.

Training of basic contact flying skills or parts of tasks of advanced mission skills could utilize visual systems which present only simple scenes possibly with some non-realistic features i.e., augmentation (see next section) to promote learning of control and procedural skills. For example, a stark scene of an airfield with a glide path outline could be used for training of takeoff and landing. Ground attack procedures could be taught with a simple ground plane texture, an obvious target, a path outline, and/or a point of weapon impact indication shown in the scene.

The inexperienced pilot probably needs to learn flight control and procedural skills which do not demand complex or realistic visual scenes. More demanding or complex tasks, however, involving full-mission training, or training of highly experienced pilots may require very detailed, highly realistic scenes. This is likely because the highly experienced pilot probably uses very subtle cues to perform his tasks with a high degree of proficiency. In effect, the experienced pilot probably is fully capable of making the aircraft do what he wants, provided that he is given information in sufficient detail (as would occur in the real world) to achieve maximum proficiency.

The point is that the perceptual part of learning that occurs during flight training probably is different for different levels of training, tasks of different difficulty and pilots with different amounts of experience. Second, the ability to learn to ignore or adjust to extraneous effects which occur in visual simulation should be considered when decisions are made about how much to spend to remove these effects. As discussed earlier, effects which are noticed during initial viewing of a simulated scene may go unnoticed after a period of experience in the ATD.

Perceptual Training. Since a pilot in an aircraft or a simulator must undergo perceptual learning, there may be benefits in terms of training effectiveness to conduct formal perceptual training. There are at least three studies which indicate that benefits could be derived from perceptual training. Payne, et al. (1954) devoted a great deal of effort to teaching the pilot to appreciate the importance of the constant appearance of the angle between the horizon and the aim point on the runway, sometimes referred to as the "h" distance (Bell, 1951).

Sitterley (1974) investigated the degradation of performance after one to four months of no flight activity. He used a technique called dynamic rehearsal, which was the continuous dynamic presentation of all pertinent visual and cockpit informational elements of approach and landing tasks as they occurred in a simulated cockpit environment, but without any direct interaction on the part of the pilot. Sitterley's primary finding was that the dynamic rehearsal, a type of formal perceptual training, was effective for retaining flight skills without benefit of actual flight practice. He also found that the benefits of dynamic rehearsal were most strongly apparent for the highly visual portions of the flight. Sitterley believes that it is the visual/perceptual elements of flight control skills which degrade most over time, and postulated that the integration or coordination of far field perceptual cues was the critical element of the retraining.

Lintern (1978) investigated the effects of various strategies of using visual cue augmentation, i.e., providing artificial cues for glideslope and lineup. He found that an adaptive strategy for using augmenting cues, where the presence or absence of the augmenting cues depended on the pilots performance, produced better performance in the

simulator than other forms of using augmenting cues, such as continuous presentation. In the adaptive strategy, the augmenting cues were not present at all times. Lintern concluded that the effectiveness of the adaptive strategy was due to enhancing the pilot's ability to use the normally available cues. In other words, the use of augmenting cues was a form of perceptual training.

The three studies just discussed indicate that there are potential values to be realized from perceptual training. What the consequences of perceptual learning are and whether it can be formally trained is a function of the scene presented to the pilot. Scene content and information acquisition are parts of the same general issue of how to use visual displays in simulator training.

Perceptual Training and System Cost Tradeoffs. To achieve the objective of the most effective training at the lowest cost, it is the total cost in terms of time and money that is important. Tradeoffs probably can be made between the expense of producing scenes of a particular degree of complexity or with particular features, and the ability of the pilot to learn to use the scene presented. If a highly realistic, and therefore expensive, display system was specified, probably only a negligible amount of perceptual learning by the pilot would be required. On the other hand, if a lower cost system was used, which may not be very realistic in appearance, more perceptual learning by the pilot would be necessary. The ideal situation is to be able to know what combination of scene characteristic and perceptual learning requirements produce the best combination for the desired training effectiveness at the lowest cost. This issue also requires further experimentation.

Augmentation

Lintern (1979) defines augmentation feedback as the situation in which information needed to perform a perceptual-motor task is supplemented with related information from additional sources. In a broad sense, visual augmentation can be considered any additions or modifications of a visual scene that facilitate the acquiring of information. Under the broad definition, both the addition of features in a scene (which have no natural world counterparts) and enhancement of representational features would be considered augmentation. Lintern conducted an extensive review of the augmentation literature and performed an experiment on the use of augmentation to teach approach and landing skills in a simulator. From the review and his own work he concluded that augmentation is an effective means to enhance the training of perceptual-motor tasks.

In one sense, augmentation is used both in the real world and in cockpit instrumentation. For example, visual landing aids around an airport provide sources of information to a pilot that may not be easily acquired from natural sources. Predictor displays in an aircraft

cockpit can also be considered a form of augmentation (Weller, 1979). In these cases, augmentation is simply a means of providing sources of information that are more easily detected or interpreted. Use of augmentation in training, however, is intended to facilitate the learning of performance and the ability to use "natural" sources of information. The student must eventually be able to perform the tasks that are being trained without the use of the augmenting sources of information.

Lintern (1978) believes that augmentation will aid skill acquisition only if the student does not become dependent on augmenting cues at the expense of natural sources of information. Lintern's own data (1978) tend to support this hypothesis. When student pilots were presented with continuously available sources of augmented information for lineup and glideslope in the simulator, they performed more poorly on test trials than a group of students trained with augmenting cues that were gradually withdrawn as performance improved. The test trials did not incorporate augmenting cues. It is clear that augmentation, properly used, can enhance learning, but it is not clear whether the main effects are on motor learning or on perceptual learning. It is likely that both forms of learning, which are intimately related anyway, are helped.

It seems clear that the use of augmentation has great potential for improving the efficiency of ATD training. The proper form of augmentation is likely to benefit training with any form of simulated visual scene. If there are high costs associated with achieving particular characteristics of a representational display, and the use of augmenation can compensate for not having them, cost benefits may be derived from using augmentation. For example, if the edge capacity of a CIG visual system limits the detail of areas or objects which can be represented in a scene, artificial cues may be useful for providing the information that would normally be derived from the representational features. That is, positional information or the location of an object could be displayed by means of augmentation in some form other than representationally. Also, the distortion of size, shape and appearance characteristics of objects in areas could be manipulated.VED TRANSFER OF TRAINING BENEFITS. The generality of Lintern's conclusion remains unknown.

Augmentation appears to have great potential for benefiting training in terms of efficiency and the cost of display systems required. Because so little is known about the uses of augmentation for the training of pilot skills in a simulator, all aspects of the use of augmentation just discussed are good candidates for research investigation.
RATHER THAN GRAY TO MAKE ITS SHAPE MORE APPARENT (Ritchie, 1978). The sea surface was made up of checkerboard squares and, of course, looked nothing like an ocean surface. These manipulations were made in the interest of making the afforded information more conspicuous. In effect, the scene content manipulations were a form of augmentation.

An important issue is the kinds of learning that are facilitated by augmentation and to what relative degree. Lintern (1979) has concluded that for augmentation to be effective in terms of transfer of training, a performance gain must be apparent from augmentation during training. That is, pilots who are presented with an augmented display should perform better during training than pilots who are presented a display without augmentation. If there are no differences in performance during the training stage, it is unlikely that augmentation will have improved transfer of training benefits. The generality of Lintern's conclusion remains unknown.

Augmentation appears to have great potential for benefiting training in terms of efficiency and the cost of display systems required. Because so little is known about the uses of augmentation for the training of pilot skills in a simulator, all aspects of the use of augmentation just discussed are good candidates for research investigation.

CHAPTER IV

FLIGHT CHARACTERISTICS FIDELITY

SUMMARY

Flight characteristics fidelity (FCF) is the extent to which aircraft control and response characteristics are reproduced in an ATD. It is the extent to which the ATD "feels" like the aircraft it represents. Factors that can influence FCF are: control system modeling; aerodynamic modeling; cockpit display fidelity; motion and force cue fidelity; visual display system fidelity; evaluation pilot training and expectations; and the nature of the pilot-in-the-loop evaluation processes used to evaluate FCF.

Historically, designing ATDs to have high FCF has suffered from inadequate aircraft data and from lack of quantitative, objective means of measuring ATD dynamics with respect to aircraft flight characteristics counterparts. Steps are being taken in the military to overcome both of these deficiencies. One consequence should be a lessened future reliance on subjective "tweeking" by acceptance test pilots and simulation engineers. Expanded use of specifically trained engineering test pilots for final system "tweeking" also should expedite the FCF acceptance process and result in better accepted ATD flight characteristics fidelity.

High FCF is very important to user acceptance of ADTs that "fly." Available information suggests that departures from high FCF may not significantly detract from an ATD's training effectiveness, at least for the final approach and landing task. The same may be true for other tasks where ATD training involves learning much more than precise, reflexive control skills. On the other hand, the issue of aircrew safety is involved, and objective data simply are lacking that deal with FCF requirements for effective, safe training on the broad spectrum of flying tasks required by military missions. It is reasonable to say, however, that many ATD users have largely unjustified concerns that negative training will result if FCF is not extremely high.

Pursuit of high levels of FCF is a given. Yet, many ATDs exist which, in various ways, have FCF shortfalls. Based on the meager evidence that is available, guidelines are given for estimating influences of FCF on training effectiveness as a function of: pilot experience; pilot skill level; task difficulty; and first-flight proficiency requirements. The guidelines are general. The primary intent of doing so is to encourage objective tests and evaluations of training that actually can be accomplished in ATDs with perceived FCF shortcomings.

INTRODUCTION

The term flight characteristics fidelity (FCF) is used in this chapter because it has not been widely used in the past and is relatively immune from connotational influence. Common terms similar in meaning are: simulator feel; handling qualities fidelity; fidelity of simulation; simulation fidelity; flying qualities; flying performance; and simulator realism. FCF is a term meant to encompass all of these similar meanings. FCF is the reproduction in an ATD of aircraft control and response characteristics.

FCF is affected by many inter-related factors, all of which combine to produce the perception of aircraft flight characteristics in an ATD. These factors, although acting in concert, can be separated for discussion, and include:

- Control inputs from the pilot;
- Control fidelity;
- Aerodynamic modeling equations;
- Sound system fidelity;
- Cockpit display fidelity;
- Motion cue fidelity;
- Out of cockpit visual system fidelity;
- Sound perception;
- Perception of cockpit display response;
- Perception of motion and force cuing system responses;
- Perception of out of cockpit visual cues;
- Pilot expectations; and
- The FCF evaluation process used.

Although factors influencing perceptions of FCF can be separated easily for discussion, they are in reality highly inter-related, both technologically and in terms of user values. Figure 2 shows key factors influencing user judgements of flight characteristics fidelity. The figure is general, but is intended to convey the complexity of issues involved in achieving user-acceptable levels of FCF.

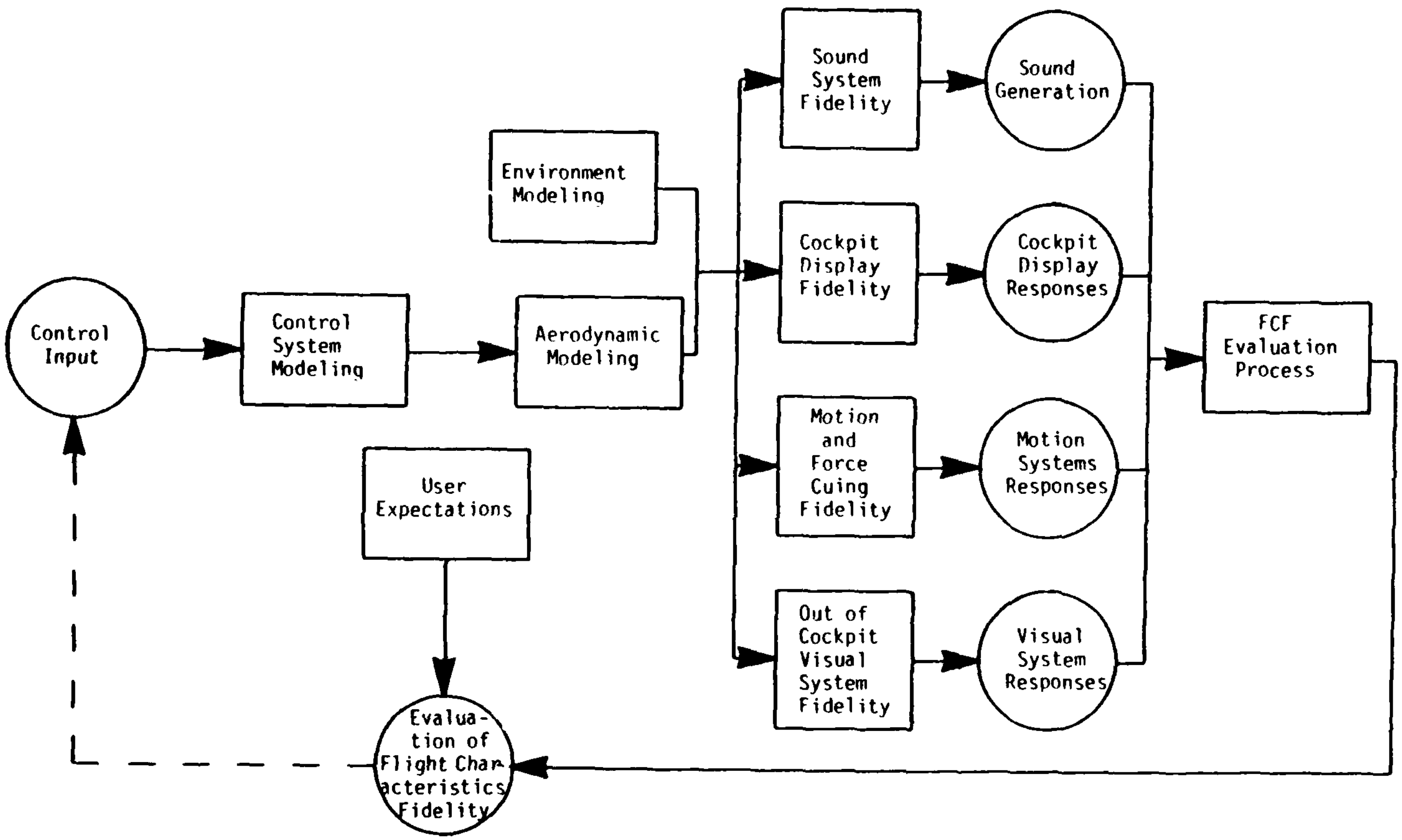

Figure 2. Factors Influencing Flight Characteristics Fidelity Judgements

Technical details of FCF are beyond the scope of this chapter. Several general points are relevant, however. The first involves historical inadequacies in the availability of needed aircraft response data, including stability derivatives. Typically, many of these needed data have not been available to ATD manufacturers. The net effect has been a strong reliance on acceptance pilots and ATD engineers to "tweek" ATD software to achieve FCF acceptance. The Air Force now requires aircraft manufacturers to provide simulator-related flight data so that more objective approximations of flight characteristics can be made during ATD design. At least one airline recently undertook highly instrumented flights with the specific purpose of obtaining data to be used to fine tune flight characteristics of one of their families of ATDs.

A second issue involves the knowledge and skills of pilots who evaluate ATD flight characteristics. Very often, senior instructor pilots are tasked with evaluating the flight characteristics of a new training device. They are not specially trained for the tasks they must perform. A trend is under way, however, to use specially trained engineering test pilots to evaluate flight characteristics fidelity (e.g. Woomer and Carico, 1977). The use of such specially trained pilots, in conjunction with appropriate flight test criterion data, serves to minimize subjectivity in FCF evaluation and modification. Evidence has been cited, however, that pilots will accommodate to ATD cues and responses after as short a period in the ATD as 30 minutes (Eddowes, 1977; Harris, 1977; Woomer and Carico, 1977; and Rust, 1975). Beyond this time, even FCF evaluations by specially trained acceptance test pilots can be inaccurate.

ATD manufacturers express desires for even more objective (quantitative) evaluations of FCF. Until this is possible, the use of specially trained evaluation test pilots and the acknowledgement of human limitations in the test and evaluation process should serve to minimize subjectivity and pilot-to-pilot differences during ATD FCF acceptance tests. In summary, the process of achieving and evaluating ATD FCF still is not simple.

A third issue involves "levels" of FCF needed for effective training. Effective ATD training depends on user acceptance of the training device. Lack of acceptance usually translates into ineffective and/or inefficient ATD use. Device acceptance, in turn, often depends on FCF levels which cannot be measured objectively with present technology. This state of affairs continues to fuel arguments between those who contend that high FCF is necessary for aircrew training, and those who oppose this view as being universally true. While there is little training effectiveness information directly dealing with FCF requirements for training, available research suggests that moderate to low levels of FCF are sufficient for many hands-on training applications. These findings are due to the fact that much more than reflexive control habit patterns is learned during ATD training. At

the same time, the issue of aircrew safety is involved, and objective data simply are lacking that deal with FCF requirements for effective, safe training on the broad spectrum of flying tasks required by military missions.

The balance of this chapter draws upon available training effectiveness information, which is meager. User FCF expectations are acknowledged, and their importance is not denied. On the other hand, available training effectiveness information suggests that high levels of FCF are not necessary for many hands-on training applications. Guidance is given on the use of ATDs with perceived FCF shortfalls. The objective of doing so is to encourage objective test and evaluation of training that actually can be accomplished in such devices, so that operational readiness can benefit.

USER EXPECTATIONS AND ASSUMPTIONS

The best ATD design is worthless if it is not accepted and used. Program interviews and the literature are conclusive on the point that low level FCF devices are not well accepted either by instructors or students for mission oriented training (McFadden & Joas, 1978; Harris, 1977; Woomer & Carico, 1977; Catron, 1975; Rust, 1975). Users prefer the closest FCF representation of actual flying if they cannot be in the air. It should be remembered, however, that preference is not proof of need.

Pilot preference for flying is not unexpected. However, it can make the gaining of ATD acceptance a difficult task. To further complicate the matter, there is evidence that pilots expect ATDs to fall short in the area of flight characteristics fidelity. As a result, they often hold negative attitudes toward some ATDs. They assume that high levels of FCF are necessary to achieve high positive transfer of training for flight control tasks, and that lower levels of FCF result in negative transfer to the aircraft (Woomer and Carico, 1977; Catron, 1975). While the following discussion of user expectations and assumptions is relatively short, its importance should not be underestimated. High FCF is the most widely used key to gaining user acceptance for "flying" ATD's. Without that acceptance, effective use of a "flying ATD" is highly unlikely, regardless of its potential training value.

AVAILABLE LITERATURE

User opinion literature is much more plentiful than the training effectiveness literature. Examination of both bodies of literature reveals strong disagreement between ATD users and the researchers investigating ATD fidelity requirements. Users, feel strongly that high levels of FCF fidelity are necessary to achieve high positive transfer of training (McFadden and Joas, 1978; Woomer and Carico, 1977; Catron, 1975; Rust, 1975). This opinion was reinforced during program site

visits. Researchers, on the other hand, claim that high levels of FCF are not always necessary to achieve effective training (Bunker, 1978; Crosby, et al., 1978; Ryan et al., 1978; Waag, 1978; Caro, 1977; Eddowes, 1977; Caro, 1976; USAF-SAB, 1973; Bryan and Regan, 1972; and Wood, et al., 1972). Some researchers further claim that low levels of FCF can be compensated for by more highly trained instructors (Eddowes, 1977; and Muckler et al., 1959). Such disagreement may be more a function of established viewpoints on the part of both groups than of empirical evidence. As is traditional in such disagreements and as discussed earlier in this section, they usually result from a lack of comprehensive, verified and accepted research.

RESEARCH OVERVIEW

The present inability to objectively quantify and scale FCF makes difficult the generalization of the limited research that exists. No studies were found that examined all of the components of FCF shown previously in Figure 2. Results discussed here are based on research addressing FCF components. Further caution must be exercised due to the relative nature of FCF. What is considered to be a high level FCF device in one setting at one time may, in another setting, or the same setting at a later time, be considered a low level FCF device. There are other restrictive influences discovered in the review of the research findings. They are discussed in the following paragraphs.

Training tasks used in available research represent only the middle of the performance envelope for both the aircraft and the pilot. These were tasks which, if performed in the air, would tax neither the pilot's nor the aircraft's performance capabilities.

Experienced pilots were used to fly elementary profiles, such as executing a three minute turn while maintaining speed and altitude in clear air. In some ways, these tasks negate FCF requirements, since good pilots can perform such basic maneuvers regardless of subtle FCF differences.

No specific aircraft has been simulated. Flight characteristics fidelity means the reproduction, or lack there of, of aircraft control and response characteristics in an ATD. Strictly speaking, if there is no specific aircraft being simulated, there can be no flight characteristics fidelity of simulation, much less a measure of the fidelity or the supposed effects.

Measures of transfer of training are not included (see Gundry, 1975). Transfer measures are the ultimate metric of training success in that the ultimate goal of aircrew training is to produce operationally ready skills during flight. Without some measure of transfer effectiveness, training success only can be estimated. The number of training effectiveness studies is very limited, which limits the extent to which findings can be generalized.

TRAINING EFFECTIVENESS RESEARCH

In a review of the state-of-the-art in 1973 (U.S. Air Force Scientific Advisory Board, 1973), the following facets of FCF were determined to have achieved adequate technology for training purposes: flight control fidelity; auditory fidelity; and cockpit flight display fidelity (for most training applications).

These findings appear to hold true for most FCF-related training applications today. Since 1973, significant progress has been made in simulation modeling technology. These advances have moved FCF technology into the zone of user acceptance.

There has been little recent research on the design of auditory cuing, such as: engine sounds, wind noise, hail and rain effects, and artificial cues such as stall warning alarms. The relatively low costs associated with extremely accurate auditory simulation capabilities, however, obviate the need for such research, even though their ATD training values are unknown.

While platform motion and visual system research is discussed in other chapters of this report, one recent study deserves mention here by way of example. Ryan, et al. (1978), while examining the effects of platform motion on P-3 pilot training performance on final approach and landing, concluded:

> "The study results indicate that simulator practice in landing pattern air work and the final phase of landing transfers positively to the aircraft. This transfer occurs even though the instructor and student pilots universally agreed that the (ATD) does not handle like the aircraft during the final phase of landing."

High levels of FCF may not be required for effective training of tasks such as individual landing, at least under the particular circumstances studied by Ryan et al. The question of greater training effectiveness as a function of improved handling characteristics fidelity was not addressed in the Ryan study.

Effects of different levels of FCF on training effectiveness are not known. Harris (1977) stated "...no relationships are published which relate training effectiveness and flying qualities and performance simulation fidelity..." Literature research in the present program found the same to be true. There are, however, two studies that relate aerodynamic equation levels to piloting performance (Ellis, et al., 1967; and Wilkerson, et al., 1965). The findings of these studies were that piloting performance was not significantly affected by degraded aerodynamic models used. The studies, however, used experienced pilots flying basic maneuvers in a research simulator not programmed to be

representative of the handling of any specific aircraft. These studies also are aged. The FCF issue lost much of its importance with the advent of digital simulation technology which enabled considerably improved flight characteristics fidelity.

CURRENT TRAINING PRACTICES

Actual training practices seem to lend support to the argument that less than high FCF is adequate for many training applications. The following current practices are offered as examples.

> Air-to-ground weapon delivery training in T-37 aircraft simulation has been shown to transfer positively to airborne performance in F-5 aircraft (Gray and Fuller, 1977).
>
> Tactical fighter lead-in training in F-5 aircraft is expected to transfer to the F-4. No evidence was found that this transfer did or did not occur, even though the F-5 must be considered a low HCF level simulation of the F-4.
>
> Contracted air refueling training in a device only approximating C-5 aircraft flying characteristics has been shown operationally to transfer positively to inflight refueling performance in the C-5.
>
> Formation flight training in T-38 aircraft is reported to transfer positively to formation flight performance in the FB-111.

FUTURE PRACTICES

One remaining technological problem area is that of aerodynamic equation specification and evaluation. The aerodynamic data supplied by airframe manufacturers to ATD manufacturers historically and presently is full of "holes" (McFadden and Joas, 1978; Harris, 1977; Iffland and Whiteside, 1977; Woomer and Carico, 1977; Catron, 1975; Rust, 1975). The holes are filled either by expensive instrumented test flights, estimation, or "tweaking".

The general consensus from simulator users and manufacturers is that much of the missing data can be supplied by airframe manufacturers through an extension of current instrumented airworthiness certification flight procedures. To achieve this requires the specification of such data in the aircraft procurement process, and should only minimally escalate the costs of a given aircraft. Methods of developing specifications and evaluation technologies have been in process for several years (Muth and Finley, 1978; Harris, 1977; Iffland and Whiteside, 1977; Woomer and Carico, 1977; Catron, 1975; Modrick, 1975). The Air Force recently has issued a data item requiring FCF-related data

for each new aircraft procurement. This Air Force step should greatly improve the current situation.

Presently, however, "tweaking" remains the common method for obtaining acceptable FCF. At best, tweaking is an arduous, iterative, time-consuming process which requires considerable skill to achieve "acceptable" FCF. It involves the iteration of subjective reporting by test pilots which is translated by simulator engineers into modifications of ATD response characteristics.

The tweaking of a series of highly interactive simulator equations to provide acceptable FCF remains an art. The successful tweaker is the individual who effectively alters terms inherent to the ATD inner and outer loop equations to provide acceptable dynamic responses from the device. He often guards the techniques he has found successful by never fully admitting how he does it, perhaps to maintain the black art secretiveness of an expert, and perhaps because he cannot explain (teach) what he does intuitively.

A CONCEPTUAL FCF TRAINING EFFECTIVENESS FRAMEWORK

This section presents a conceptual framework from which rational decisions regarding FCF requirements may be made. The discussion assumes that the reader has reviewed the introduction to the fidelity volume and preceding material in this chapter. Particular emphasis is called to the remarks concerning the matching of training content, cuing and response requirements to device characteristics, and to those addressing the need to specify student skill levels prior to specifying device requirements.

Performance Envelope Concept

Hardware and aircraft designers have, for many years, designed equipment to meet specified performance parameters. The accumulated range of performance parameters has been referred to as the "performance envelope" for the particular hardware (aircraft) system. Hardware modifications frequently are undertaken to add additional performance capabilities to the system. This is viewed as an expansion of the system's performance envelope.

Performance capabilities of pilots and student pilots can be viewed in the same fashion. The performance envelope for a pilot consists of the accumulation of his piloting skills including landings, takeoff, air to air combat, decision making, etc. Training, in the same context, can be viewed as an expansion of the pilot's performance envelope.

This concept, taken into an additional dimension, can be applied to the pilot/aircraft system (P/AS) context. Total system performance is limited both by aircraft capabilities and pilot skills. There is, as such, a total pilot/aircraft system performance envelope. This

performance envelope is unique for every pilot/aircraft system combination.

Just as the performance envelope for each pilot/aircraft system is itself unique, so are the limits or boundaries of each performance envelope. A pilot may be capable of flying Mach 2.5 at 50,000 ft., but if the aircraft is capable of only Mach .9, the limit of the P/AS is Mach .9. Conversely, an aircraft may be capable of out-maneuvering an adversary aircraft, but if the pilot cannot perform the required maneuvers, the P/AS is limited by the pilot.

Performance Envelope Limits and Training (PELTS)

The research cited in previous sections of this chapter is based almost exclusively on data from the middle of the performance envelope of both aircraft and pilot. There is some suggestion in the literature that training for performance closer to or beyond performance envelope limits may require higher levels of ATD FCF (USAF-SAB, 1978; Caro, 1977; Fedderson, 1962).

These suggestions, supported by observations during program site visits, have lead to development of a concept called PELTS (Performance Envelope Limits and Training). The PELTS concept suggests that relative operational task difficulty has direct relationship with the need for FCF.

PELTS is based on the five generalized relationships shown in Figure 3. Component piloting skills refer to the skills possessed by the student pilot which are directly applicable to the new task being trained. They are differentiated from general piloting experience because a highly experienced pilot can draw on unrelated experience and generalize to the new task. He does not require specific component piloting skills to the same extent that a less experienced pilot would.

Relative task difficulties (for both a pilot and the aircraft) combine with proficiency level desired to place the task being trained in a conceptual position relative to the P/AS performance envelope. Proficiency level desired is a factor which influences, but is not the same as pilot task difficulty. It is conceivable that a requirement may arise for an elementary task to be trained to absolute proficiency. While this will increase the difficulty factor for the pilot to some extent, the requirement for flawless execution under all circumstances moves the task much closer to the performance limits of the P/AS system than would be the case if only the task difficulty increase was considered.

Five generalized factors are hypothesized that combine to result in the PELTS concept. An additional observation is that tasks which are relatively easy for the aircraft to perform are generally those in which the task performance and cuing are not highly aircraft specific. Highly

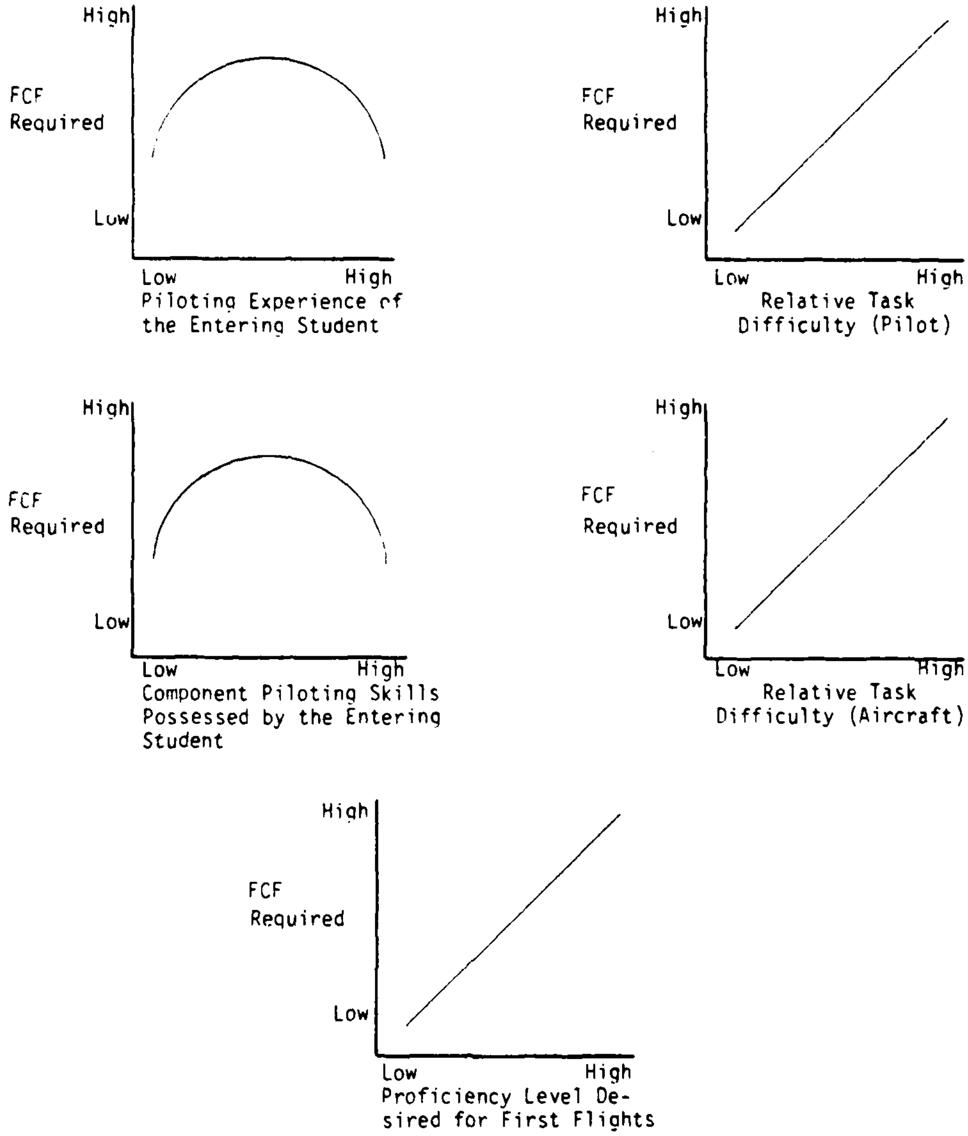

Figure 3. Five Generalized Relationships Involved in the PELTS Concept

Highly aircraft specific tasks (e.g. stall/spin recovery) generally are closer to the limits of the performance envelope.

PELTS, briefly stated, indicates:

> The requirement for FCF is diminished for trained tasks which are in the middle of the performance envelope of the pilot and aircraft system. As the trained tasks increase in difficulty and approach the performance limits of the pilot and aircraft combination, the requirement for high levels of FCF increases accordingly.

One aspect that is fundamental to this concept is that the pilot's part of the performance envelope is both multidimensional and dynamic. That is, a pilot may be able to perform a specific new flight maneuver after being instructed on one minor aspect of the maneuver if he already has been taught the other components of the maneuver in the course of previous training and can, through mediation, represent those components. When he learns the one remaining aspect, his performance envelope expands to include the entire maneuver.

The PELTS concept appears to be consistent with researcher suggestions that different FCF levels are required for beginning versus continuation pilots. PELTS implies that high levels of FCF are required only as P/AS performance limits are reached. The beginning student has no performance envelope to speak of. The tasks which he must master in order to develop a performance envelope are those basic tasks that form the core of a pilot's flying performance; i.e. the middle of the performance envelope. High FCF, levels may, in fact, inhibit learning in the beginning students by presenting a full array of cues which compete with those he is trying to learn and attend to in order to perform the rudimentary tasks of basic flying.

TRAINING TASKS DIFFERENCES

The following paragraphs are presented with the intent that a discussion of training tasks identified in the contract Statement of Work as a focus for the STRES program will expand on the PELTS concept.

Takeoff and Landing

These are two different hierarchical instructional tasks in that individual landing/takeoff skills are required of all pilots performing formation landing/takeoff. The teaching of individual landing/takeoff according to the PELTS concept requires high FCF only to the extent that the task is close to the performance limits of the P/AS. Carrier landing, for example, requires touchdown tolerances well beyond those of most other landing situations, thus requiring a higher level ATD FCF. This requirement also is limited however. The relevant flight characteristics fidelity aspects of landing are only those associated

with low speed, low altitude, and stringent approach performance criteria. For more routine, land based landing training, where the landing margin is much greater, generalized trainers with only moderate FCF levels, followed by specific aircraft familiarization training, may be sufficient.

Formation landing/takeoff is a more complex issue depending much more on the entering skill level of the pilots. It is obviously a more difficult task than individual takeoff/landing, but the critical aspect is the difficulty of the tasks (skills) to be trained. For example, the teaching of formation takeoff/landing to experienced pilots, familiar with their specific aircraft, thoroughly proficient in individual takeoff/landing and close formation flight, may require no device training at all. Effective training for that group might be achieved simply through a directed group discussion addressing the unique cues and problems encountered in the task. The remaining parts of the task would be represented through cognitive training.

Conversely, new UPT graduates with less practiced individual landing/takeoff skills, little specific aircraft experience, and little formation flight experience, probably would require a device with moderate to high levels of FCF, followed by inflight practice.

Formation Flight

Under normal conditions, this is a task well within the response capabilities of the aircraft, and depends, for the most part, upon pilot skills. Pilots familiar with their aircraft flying characteristics through prior experience should require only moderate levels of FCF in a training device, with primary emphasis placed on out of cockpit visual cues (Wood, et al., 1972).

Inexperienced pilots, not familiar with the flying characteristics of the specific aircraft, should find formation flight tasks closer to the limits of their performance envelope. To attain a given proficiency level, these pilots might require higher levels of ATD FCF.

Aerobatics

The training of aerobatics appears to have a two-fold nature and thus two different sets of FCF requirements. The teaching of execution techniques is essentially the same for all aircraft. As such, the training of aerobatic techniques would seem to require only moderate levels of FCF (such as those found in a generalized trainer). On the other hand, aerobatics maneuvers frequently are executed at or close to the performance limits of the P/AS. The flying of aerobatics in the air can be an aircraft-specific task at the edges of the performance envelope, and as such would require higher levels of FCF.

ATD FCF requirements thus depend on specific training objectives. If execution techniques are taught as part of early pilot training, a generalized device could be sufficient, provided that it is later followed with specific aircraft instruction. If it is incorporated as a part of mission or aircraft familiarization or continuation training, however, higher FCF levels may be required.

Spin, Stall and Unusual Attitudes

These tasks present two different sets of training problems. Spin and stall recognition, prevention and recovery are highly aircraft specific, and, by definition, are at or beyond the performance envelope limits of the P/AS. Conversely unusual attitude (e.g. inverted flight) recognition and recovery are common to most aircraft types, and not necessarily close to the performance limits of a P/AS.

Spin and stall recognition, prevention and recovery, as mentioned above, are highly aircraft-specific and are tasks performed as the P/AS approaches its performance limits. As has been demonstrated in training practice (A-7 stall departure), high FCF appears necessary for effective training. Recovery from and prevention of stalls and spins also is highly aircraft specific and performed at the limits of the P/AS. As a result, they would require high FCF levels for effective, comprehensive training.

Terrain Following/Terrain Avoidance

These tasks involve two sets of training requirements because two modes of operation (autopilot versus manual control) are involved. Aircrew monitoring of autopilot performance in terrain following/terrain avoidance is largely a perceptual pattern recognition task which probably could be taught efficiently in a functional procedures trainer. The critical aspect of the P/AS performance in this task is real time reaction to a given set of cue patterns (e.g. indicating autopilot failure). The P/AS, in this mode, is well within its performance envelope.

Terrain following/terrain avoidance under manual control is an entirely different training requirement. This task is performed at the limits of the pilot's performance envelope (more so than the aircraft, generally) particularly in the domains of psychomotor reaction time and perceptual accuracy. The training of manual control of this task would, therefore, require high levels of FCF in that the pilot is performing at the limits of his performance envelope, meaning that the P/AS is at its limits as well.

Air to Air Combat

While having the same general intent, air-to-air missiles and aircraft mounted guns are used in different manners, requiring different

training approaches and different hardware requirements. Radar missiles generally are used at "long" range, and aircrew tasks are mostly systems monitoring and manipulation. The flying tasks associated with proper execution of a radar missile launching usually are well within the P/AS performance envelope. In light of these circumstances it seems that lower FCF devices could be effectively used for aircrew training in long range missile attack.

Air to air combat using guns or short range missiles is a different task. The speeds, accelerations and maneuvering involved in the use of these weapons are far more demanding of the P/AS. The performance of this task requires performance close to or at the performance limits of the P/AS. According to the PELTS concept, achieving high positive transfer of training would require high levels of FCF.

<u>Air to Ground Weapon Delivery</u>

This is largely a visual task, usually performed under conditions well within the performance envelope of the aircraft and pilot. Training here is generally centered around proper aircraft orientation and positioning, and timing. As such, generalized trainers with moderate levels of FCF should prove effective. This view is generally supported by the findings of Gray and Fuller (1977). They trained recent UPT graduates to perform dive bombing tasks in a simulation of the T-37 aircraft. The students then were tested in flight using the F-5 aircraft. The simulator training transferred very well to inflight dive bombing performance, even though the flight characteristics of the simulator and aircraft used were quite different.

CONCLUSIONS

Flight characteristics fidelity (FCF) is the extent to which aircraft control and response characteristics are reproduced in an ATD. It is the extent to which the ATD "feels" like the aircraft it represents. Factors that can influence FCF are: control system fidelity; aerodynamic modeling; cockpit display fidelity; motion and force cue fidelity; visual display system fidelity; evaluation pilot training and expectations; and the nature of the pilot-in-the-loop evaluation processes used to evaluate FCF.

Historically, designing ATDs to have high FCF has suffered from inadequate aircraft data and from lack of quantitative, objective means of measuring ATD dynamics with respect to aircraft flight characteristics counterparts. Steps are being taken in the military to overcome both of these deficiencies. One consequence should be a lessened future reliance on subjective "tweeking" by acceptance pilots and simulation engineers. Expanded use of engineering test pilots for final system "tweeking" also should expedite the FCF acceptance process and result in better accepted ATD flight characteristics fidelity.

High FCF is very important to user acceptance of ATDs that "fly". The research literature suggests that departures from high FCF may not significantly detract from an ATD's training effectiveness, at least for the final approach and landing task. The same may be true for other tasks where ATD training involves learning much more than precise control skills. On the other hand, the issue of aircrew safety is involved, and objective data simply are lacking that deal with FCF requirements for effective, safe training on the broad spectrum of flying tasks required by military missions. It is reasonable to say, however, that many ATD users have largely unjustified concerns that negative training will result if FCF is not extremely high.

Pursuit of high levels of FCF is the rule. Yet, many ATDs exist which, in various ways, have FCF shortfalls. Based on the meager evidence that is available, guidelines are possible for estimating influences of FCF on training effectiveness as a function of: pilot experience; pilot skill level; task difficulty; and first-flight proficiency requirements. The guidelines are general. Their primary intent is to encourage the objective test and evaluation of training that actually can be accomplished in ATDs with perceived FCF shortcomings.

CHAPTER V

PLATFORM MOTION SYSTEMS

SUMMARY

Platform motion systems that provide from three to six degrees of freedom of cockpit movement are relatively common in modern operational flight trainers, full mission trainers, and certain part-task trainers. Motion system hardware, computing and software variables all can impact the quality of the motion cues that are generated. Cue quality, in turn, can influence pilot acceptance and, possibly, training effectiveness.

Platform motion cuing is assumed to benefit training because it contributes to the realism of the training environment. Research on the training effectiveness of motion cuing, although extensive, is not conclusive. Anecdotal evidence also suggests that, in some cases, pilots are unaware of whether platform motion systems have been turned on or off. These cases almost always involve ATDs with out of cockpit visual display systems, which can provide motion cuing information.

Much of the motion cuing research has dealt only with pilot performance in the simulator. Relatively few studies have investigated differences in performance in actual aircraft following simulator training with or without platform motion cues (i.e. *transfer of training* studies). Recent transfer of training studies investigating the impacts of platform motion cues during ATD training have found that the presence of platform motion cues did not lead to improved pilot performance during subsequent inflight tests. A number of these studies have been criticized, however, on the basis that lags in the motion systems used and problems in drive algorithms and computation have resulted in findings that are difficult to interpret. The measurement of pilot performance in flight also is a very difficult task, and the possibility remains that the inflight measures used were insensitive to subtle differences in pilot performance and technique. Finally, the available transfer of training experiments all involved tasks where cockpit motion feedback is the direct result of pilot control inputs, rather than disturbances outside the pilot-aircraft control loop.

One line of current reasoning seems to account for apparently contradictory findings from many studies and experiences dealing with the training value of motion cuing. Motion cues are viewed in two categories: maneuver motion cues; and disturbance motion cues. Maneuver motion is a pilot-initiated, closed loop function. The most important element is that the pilot expects the motion cue feedback; thus, maneuver motion confirms execution and control. It does not necessarily tell the pilot anything new. Disturbance motion, on the other hand, is not pilot initiated. Examples include yaw following engine failure, buffet, turbulence or responses to vehicle

instabilities. Disturbance cues provide new information to the pilot, who must react to control the aircraft.

It may be that disturbance motion cues are important to ATD training, but that maneuver motion may not. Although much of the available evidence supports this view point, there are no relevant transfer of training data to support the assumed importance of disturbance motion during ATD training. Also, evidence only recently has become available addressing the issue of whether out of cockpit visual systems can provide adequate maneuver and disturbance cues for training purposes. It is possible that platform motion cues may contribute little to training for certain objectives in the presence of adequate visual system cues, but available evidence is incomplete.

Some anecdotal evidence was found suggesting that motion cuing may be necessary for ATD training involving high workload levels and pilot timesharing between flight control tasks and sensor operation tasks in a high threat environment. It is possible in this or other cases that motion cues act as disturbance cues by alerting the pilot to make corrective control inputs. The training value of motion cuing in very high workload situations, especially using sensors, is an issue requiring further research.

Other research has shown that instrument use, the use of flight controls, and tracking performance in simulators are more apt to be like these behaviors in the aircraft when motion cues are provided in the simulation. However, no evidence exists on whether these performance details are meaningfully improved in the aircraft following ATD training incorporating platform motion. Available evidence suggests that pilots can readily adapt their control and scan strategies to inflight requirements.

Finally, there is evidence that motion cues may be of value in minimizing simulator sickness (nausea) in pilots who are susceptible to this problem. The incidence of simulator sickness is rare, however, and its occurrence usually is short lived as pilots acclimate to cue discrepancies assumed to cause the problem.

INTRODUCTION

This chapter deals with the effectiveness of platform motion systems for aircrew training, and pilot training in particular. Platform motion system technology is discussed first. Related fidelity features, force cuing systems and out of cockpit visual systems then are discussed, and their relationships are explained. Assumed instructional values of platform motion cues then are presented. Training effectiveness, training efficiency and user acceptance assumptions are addressed. A conceptual training effectiveness framework then is presented as an aid in determining the need for a training effectiveness of platform motion cues. Available training effectiveness data then are discussed.

In-simulator pilot performance then is addressed, together with pilot opinion information.

PLATFORM MOTION TECHNOLOGY

Platform motion systems are designed to provide realistic representations of motion cues found in the flight environment. The technology of research and development on platform motion systems has involved two areas: 1) production of hardware and software capable of producing realistic motion cues; and 2) understanding and modeling the human sensory system in order to better define the nature of the cuing process as an information source to the pilot.

Platform motion system hardware and technology have been refined many times since the development of early, crude platform motion systems. The general characteristic, however, has been fairly consistent. The motion system supplies a platform for the pilot and provides cues that change his position or orientation in some (or many) direction(s). Motion platforms have used a wide variety of hydraulic, pneumatic, electrical, and mechanical means to impart motion cues, and can be characterized generally by the range, direction and dimension of accelerations they provide before encountering engineering limitations or motion stops (Huff and Nagel, 1975). Puig, Harris, and Ricard (1978) point out that platform motion systems have been designed from as early as 1918 to provide from one to six degrees of freedom using many types of power/drive techniques, ranging from pneumatic bellows and cables to cascaded gimbals or large amplitude beams.

In the 1960's, a synergistic, six degree of freedom (DOF) motion platform was developed using relatively simple hardware. This design concept is still considered state-of-the-art by many users. Today, most motion systems used for ATD's incorporate the synergistic structure of hydraulic supports. Because there are 6 DOF (3 angular axes: roll, pitch and yaw; and 3 linear axes: longitudinal, lateral and vertical), it is costly to design all 6 DOFs with wide ranges of acceleration and physical displacements. For this reason, even the most advanced ATD platforms are more capable of producing some accelerations and positions than others.

Platform motion systems are driven by computer algorithims, which were the subject of increased refinement in the 1970's (Puig, Harris and Ricard, 1978). The ability of digital computers to solve complex equations of motion accurately, reliably and within shorter delay limits was one reason for changing to digital technology for ATDs.

Digital computers also brought the flexibility to rapidly change simulated aircraft parameters. Other areas of refinement included improved iteration rates, hydraulic support seals, and system feedback mechanisms. All of these hardware and software development areas tended to improve platform response and lessen the "mechanical feel" of ATDs.

System types which presently are found in operation include: synergistic platforms; cascaded systems; beam systems; centrifuges; and suspended systems (hung from overhead). While the first four types are common, suspended systems are not.

Tables 11 and 12, taken from Puig et al., 1978, provide a broad spectrum listing of commercial and military ATDs and their motion system characteristics.

While platform motion technology has been refined considerably in 60 years of research and development, there still are technological shortcomings. A basic limitation is that platform motion systems are physically large and often do not have the responsiveness of actual aircraft. Further, they are ground-based and do not produce many of the sustained accelerational cues of flight. This factor means that, for the most part, platforms are capable of simulating the leading edge of the acceleration cues, or onset cues. Such a limitation restricts the fidelity of platform motion cues in comparison with the actual flight environment.

Improved understanding of the human sensory system as it receives motion cue information has been an important step toward refining platform motion systems. By understanding the vestibular and haptic (skin pressure) responses arising from piloting an aircraft, it is possible to better recreate in an ATD the cues which elicit those responses (Kron, 1975). It is important to note the presence of visual cue perception as a part of models of the human sensory system. While pilots receive cues from the vestibular senses and the haptic pressure receptors, visual receptors also play an important role in the perception of motion. The section titled Field of View Requirements in Chapter III of this report expands on this point.

RELATED FIDELITY FEATURES

The literature and information gathered during program site visits suggest a strong relationship between platform motion systems, out of cockpit visual systems and force cuing devices. These relationships are discussed in the following paragraphs.

Visual Systems

The relationship between platform motion systems and visual systems is a highly complementary one. It should be noted that while this relationship is complementary, it also is delicate. When these systems are combined, the integration should eliminate unacceptable delays between related cues provided by motion and visual systems. Large delays can result in disorientation and simulator sickness (Puig et al., 1978). The interaction of these two systems also influences the performance of pilots in ATDs. (See Chapter VII of this report for additional discussion of cue synchronization.)

ORGANIZATION	SIMULATOR NAME	ANGULAR PERFORMANCE IN RADIANS & SECONDS								
		ROLL			PITCH			YAW		
		EXCUR	VEL	ACCEL	EXCUR	VEL	ACCEL	EXCUR	VEL	ACCEL
NASA-Ames	Flight simulator for Adv. Aircraft	±0.79	±1.77	±4.0	±0.40	±0.7	±2.0	±0.52	±0.7	±2.0
NASA-Ames	Six-degree of freedom flight simulator	±0.61	±1.3	±10.0	±0.61	±1.7	±4.5	±0.61	±3.0	±3.0
NASA-Ames	Height control test apparatus HYCONTA	-	-	-	-	-	-	-	-	-
NASA-Ames	Moving Tab transport simulator	±0.16	±0.22	±4.7	+0.25 -0.10	±0.22	±4.7	-	-	-
NASA-Ames	Vertical Accel roll device VARD	±0.48	±3.0	±3.0	-	-	-	-	-	-
NASA-Ames	Vertical motion simulator	±0.38	±0.26	±0.87	±0.44	±0.26	±0.8[illegible]	±0.51	±0.26	±0.87
NASA-Langley	Real-time dynamic simulator	Cont	±1.0	±1.0	Cont	±1.0	±1.0	Cont	±1.0	±1.0
NASA-Langley	Visual motion simulator	±0.38	±0.27	±2.0	+0.50 -0.33	±0.27	±2.0	±0.52	±0.44	±2.0
USAF-ASD Aeronautical Systems Div	Crew station simulation facility	±0.17	±1.3	±0.88	+0.44 -0.24	±1.7	±0.88	±0.09	±0.3	±0.9
Naval Training Equipment Ctr	TRADEC	±0.26	±0.35	±3.7	+0.35 -0.18	±0.17	±3.0	±0.31	±0.08	±0.40
Naval Training Equipment Center	AWAVS	±0.38	±0.26	±0.87	±0.45	±0.26	±0.87	±0.51	±0.26	±0.87
US Army ECOM	Tactical Avionic System Simulator	±0.26		±0.5g	±0.26		±0.5g	±0.26		±0.20
NASA-Marshall	Three-degree of freedom simulator	±0.16	±0.21	±1.0	+0.42 -0.28	±0.21	±1.0	-	-	-
NASA-Marshall	Six-degree of freedom simulator	±0.38	±0.26	±2.0	+0.52 -0.28	±0.26	±2.0	±0.54	±0.26	±2.0
USAF Flight Dynamics Lab	LAMARS	±0.43	±1.05	±8.0	±0.43	±1.05	±7.00	±0.43	±1.05	±3.50
USAF Flight Dynamics Lab		±0.17	±1.3	±0.88	+0.44 -0.24	±1.7	±0.88	±0.09	±0.3	±0.9
USAF Flight Dynamics Lab		±0.16	±0.22	±4.7	+0.25 -0.10	±0.22	±4.7	-	-	-

Table 11. Mo
Mo

ANS & SECONDS				TRANSLATIONAL PERFORMANCE IN FEET AND SECONDS									AVAILABLE VISUAL SYSTEM DISPLAY
	YAW			LONGITUDINAL			LATERAL			VERTICAL			
CCEL	EXCUR	VEL	ACCEL	EXCUR	VEL	ACCEL	EXCUR	VEL	ACCEL	EXCUR	VEL	ACCEL	
±2.0	±0.52	±0.7	±2.0	±4.0	±6.32	±10	±50	±17.0	±12	±5	±8.65	±12.0	Collimated shadow for pilot & co-pil
±4.5	±0.61	±3.0	±3.0	±9.0	±9.0	±7.5	±9.0	±8.0	±9.2	±9.0	±7.5	±8.8	Real world for hov uncollimated monit for other studies
-	-	-	-	-	-	-	-	-	-	±50	±18	±22	Real world or collimated monitor
±4.7	-	-	-	-	-	-	-	-	-	±2.0	-	±32	Collimated monitor for pilot & co-pil
-	-	-	-	-	-	-	-	-	-	±10	±12	±64	Collimated monitor for pilot & co-pil
±0.8	±0.51	±0.26	±0.87	±4.0	±2.0	±16.1	±20	±10	±24	±30	±20	±33	Collimated color monitor
±1.0	Cont	±1.0	±1.0	±75	±6.0	±6	±6	±4	±6	±20	±6	±5	Monitor or real world
±2.0	±0.52	±0.44	±2.0	±4.1	±2.3	±19	±4.0	±2.2	±19.2	±2.4 -3.2	±1.3	±32	Color
±0.88	±0.09	±0.3	±0.9	-	-	-	±0.5	±1.3	±20	±2.0	-	±25.6	525- & 1000-line tors from modifie SMK-23's
±3.0	±0.31	±0.08	±0.40	-	-	-	-	-	-	±1.0	±1.0	±24	B/W CIG monitor picture
±0.87	±0.51	±0.26	±0.87	±4.0	±2.0	±16.1	±3.5	±2.0	±19.32	±2.25	±2.0	±25.76	TV projection ont foot diameter dom Image generation: camera/model or C
±0.5g	±0.26		±0.20g	-	-	-	-	-	-	±0.5		±16	3 CRT's with col mating pancake w
±1.0	-	-	-	-	-	-	-	-	-	±1.0	±1.25	±25	48-degree B/W TV pancake collimat optics
±2.0	±0.54	±0.26	±2.0	±4.0	±2.0	±19	±4.0	±2.0	±19	±2.9	±2.0	±32	Above hardware available
±7.00	±0.43	±1.05	±3.50	-	-	-	±10	±10	±64	±10	±10	±97	Camera/model & e projector; targe
±0.88	±0.09	±0.3	±0.9	-	-	-	±0.5	±1.3	±20	±2.0	Yes	±25.6	Non-pupil formin collimated color
±4.7	-	-	-	-	-	-	-	-	-	±2.0	Yes	±32	Non-pupil formin collimated color

Table 11. Moving Base Research Flight Simulators or Motion Systems for Government

CCEL	AVAILABLE VISUAL SYSTEM DISPLAY	GENERAL COMMENTS
12.0	Collimated shadow mask for pilot & co-pilot	Three-man cockpit, aural & control loaders
8.8	Real world for hover, uncollimated monitor for other studies	One man cockpit
±22	Real world or collimated monitor	Decommissioned
±32	Collimated monitor for pilot & co-pilot	Three-man cockpit, often set up for two projects, control loaders & aural cues. Previous generation link OFT motion system, perf. is nonsimultaneous.
±64	Collimated monitor for pilot & co-pilot	Two-man cockpit
±33	Collimated color monitor	Motion system checkout complete
±5	Monitor or real world	One- & two-man cockpits
±32	Color	Link present generation OFT motion system to be outfitted with cockpit
±25.6	525- & 1000-line monitors from modified SMK-23's	Actually 3 separate modified OFT's performance data for F-111 system. Other 2 like Ames MCTS - no yaw or lat, radar land mass simulation available, flight dynamics lab has similar system.
±24	B/W CIG monitor picture	Used for trainer research, CAE 4DOF motion system F-111 equiv. cockpit
±25.76	TV projection onto 20-foot diameter dome. Image generation: camera/model or CIG.	Background TV channel is low resolution, wide angle. The target TV channel's narrow FOV presents a high resolution image for insertion into background channel.
±16	3 CRT's with collimating pancake windows	Two upgraded SMK-33's with identical models for visual image gen. two identical cockpits and motion systems.
±25	48-degree B/W TV with pancake collimating optics	Upgraded SMK-23 available as part of lab
±32	Above hardware available	
±97	Camera/model & earth/sky projector; target A/C	
±25.6	Non-pupil forming, collimated color	Fighter cockpit
±32	Non-pupil forming, collimated color	Transport cockpit

ORGANIZATION	SIMULATOR NAME	ANGULAR PERFORMANCE IN RADIANS & SECONDS								
		ROLL			PITCH			YAW		
		EXCUR	VEL	ACCEL	EXCUR	VEL	ACCEL	EXCUR	VEL	ACCEL
A	Six-Degree of Freedom Motion System	±0.33	±1.7	±7.2	±0.23	±1.2	±4.2	±0.33	±2.7	±13.0
B	Three-Degree of Freedom Motion Simulator	±unk	±4.8	±40	unk	±4.8	±40	-	-	-
C	Flight Training Simulator	±0.35	±0.27	±0.35	+0.50 -0.33	±0.27	±0.52	±0.44	±0.35	±0.35
D	4 DOF Mo. Sys.	±0.26	±0.30	±0.87	±0.26	±0.26	-		-	
E	Small Amplitude Motion System	±0.35	±1.6	±2.00	±0.18	±0.90	±23	±0.18	±0.90	±22
F	Large Amplitude Motion System	±0.26	±0.52	±6.00	±0.19	±0.31	±1.0	±0.19	±0.28	±2.0
G	Moving Base Simulator	±0.79	±1.70	±5.2	±0.52	±0.52	±1.7	±0.52	±0.52	±1.7
H	4-Degree of Freedom Dynamic Flight Simulator	±0.70	±35	±21	±0.26	±0.87	±18	-	-	-
I	HOTRAN	±0.70	±0.35	unk	±0.14	±0.35	unk	-	-	-
J	Transport A/C Sim	±0.26	±0.07	unk	+0.28 -0.14	±0.17	unk	-	-	-
K	V/STOL Simulator	±0.52	±0.61	±2.1	±0.78	±0.61	±2.1	±0.78	±0.65	±2.5
L	Large Amplitude -- Wide Angle Visual (LAS/WAVS)	±0.35	±1.0	±5.0	±0.35	±1.0	±17	±0.35	±1.0	±50
M	3-Axis Flight Simulator	Yes			Yes			Yes		
N		±0.54	±0.62	±7.8	±0.58	±0.56	±7.8	±0.69	±0.70	±7.8

Table 12. Mc
Mc

S & SECONDS				TRANSLATIONAL PERFORMANCE IN FEET AND SECONDS									AVAILABLE VISUAL SYSTEM DISPLAY
	YAW			LONGITUDINAL			LATERAL			VERTICAL			
EL	EXCUR	VEL	ACCEL	EXCUR	VEL	ACCEL	EXCUR	VEL	ACCEL	EXCUR	VEL	ACCEL	
2	±0.33	±2.7	±13.0	±0.42	±3.4	±35	±0.42	±2.2	±29	±0.42	±2.2	±65	CGI, 38 X 53, B/W 600 TV lines, collimated
)	-	-	-	-	-	-	-	-	-	±3.0	±7.0	±97	Unknown
.52	±0.44	±0.35	±0.35	±4.2	±2.0	±16	±4.9	±2.6	±16	±2.8	unk	±24	Cine Projector wi Servoed speed & o
-		-					±1.25	±1.25	±6.4	±1.0	±1.0	±32	B/W projector or collimated monito
3	±0.18	±0.90	±22	-	-	-	±1.0	±5.4	±144	±1.0	±5.4	+176 -112	20ϕ spherical scr for projection of or camera model i
.0	±0.19	±0.28	±2.0	-	-	-	±5.0	±10	±19.3	±10	±20	±62.4	
.7	±0.52	±0.52	±1.7	-	-	-	±5.0	±5.8	±32	±10	±13.5	±100	25" collimated mo for color camera/ or CGI
8	-	-	-	-	-	-	±2.0	±10	±22	±10	±14	±161	TV monitor & Targ camera/model syst project horizon s
nk	-	-	-	-	-	-	-	-	-	±0.50	±0.83	Unk	Point light sourc be able to mount from camera model
nk	-	-	-	-	-	-	-	-	-	-	-	-	SMK-23 @ upgraded optics by monitor or projector
2.1	±0.78	±0.65	±2.5	±5.0	±3.0	±32	±5.0	±3.0	±32	±2.5	±3.0	±32	TV monitors @ CGI
17	±0.35	±1.0	±50	-	-	-	±10.1	±10	±51	±10.4	±13	±97	Various including camera model & horizon projecto
	Yes												200 Horiz point l source
7.8	±0.69	±0.70	±7.8	±5.4	±5.9	±48	±5.6	±6.0	±46	±3.5	±3.3	±53	Collimated color monitor

2

Table 12. Moving Base Research Flight Simulators or Motion Systems for Industry

ERTICAL VEL	AL ACCEL	AVAILABLE VISUAL SYSTEM DISPLAY	GENERAL COMMENTS
±2.2	±65	CGI, 38 X 53, B/W 600 TV lines, collimated	One-man cockpit, control loaders
±7.0	±97	Unknown	
unk	±24	Cine Projector with Servoed speed & optics	Apparently identical to Langley 6-deg motion base, built as L-100 trainer; use for research is potential
±1.0	±32	B/W projector or collimated monitor	Two Camera/Model Vis. Image Gen.
±5.4	+176 -112	20ϕ spherical screen for projection of CGI or camera model images	Motion system can mount any of several 1-man or 2-man cockpits. Control loaders available
±20	±62.4		
±13.5	±100	25" collimated monitors for color camera/model or CGI	Boom-type system, generally built for fighters
±14	±161	TV monitor & large camera/model system can project horizon slide	Performance numbers are specs. boom-type system
±0.83	Unk	Point light source, must be able to mount monitor from camera model	Interchangeable cockpits, made for VTOL hover
-	-	SMK-23 @ upgraded optics by monitor or projector	Transport cockpit
±3.0	±32	TV monitors @ CGI	Franklin Inst. Pilot Model of Singer-Link 6 DOF
±13	±97	Various including camera model & horizon projector	One- & two-man interchangeable cockpits with control loaders
		200 Horiz point light source	
±3.3	±53	Collimated color monitor	Transport cockpit in-house built, Franklin Institute-type motion

3

Force Cuing Devices

Force cuing devices are addressed in depth in Chapter VI of this report. They include: G-suits; G-seats; arm and helmet loaders; seat shakers and visual system greyout/blackout capabilities. These devices are being designed to provide ATD cues associated with sustained G-force loading in flight, and/or to provide alternatives to platform motion systems for buffet and similar low amplitude, relatively high frequency cues. Force cuing technology is relatively new and untried. However, force cuing is related to platform motion cuing because force cuing devices also provide certain motion-related cues. As with visual systems, it is important that force cues be properly synchronized with other motion-related cues to avoid cue conflicts and associated performance and physiological problems. It has been suggested (e.g. Stark and Wilson, 1973) that G-cuing devices, such as G-seats, may provide cues that are highly complementary to cues produced by platform motion systems. Research and operational evidence is quite limited on this issue, however, and the actual training value of combined platform motion and force cues remains an open issue.

ASSUMED INSTRUCTIONAL VALUES

Platform motion systems are one of the more expensive fidelity features of ATDs. Estimates of life cycle cost for platform systems range up to 7% of total simulation program costs (Puig, et al., 1978). The underlying assumption which justifies this cost is that benefit to training will be achieved. The assumptions of instructional value provide criteria against which training results can be compared and goals evaluated. The assumed instructional values of platform motion systems can be categorized in three areas: 1) effectiveness of training; 2) efficiency of training; and 3) user acceptance.

Effectiveness of Training

The value of platform motion systems for increasing the effectiveness of training is a critical issue. The effectiveness of training includes the type and quality of training in the ATD and, most important, the transfer (i.e. carry forward) of that training to the operational environment. The importance of platform motion to transfer of training must be evaluated objectively and with respect to the total family of cues available, such as visual system cues. Type of training refers to the specific tasks being trained. The need for platform motion cuing must be addressed on the basis of specific training objectives, rather than a general issue (Caro, 1979). ATDs allow training programs to include emergency problems which would prove too dangerous to train in actual aircraft. A platform motion system may enchance instruction in flight regimes which would otherwise not be possible. Quality of training refers to skill performance criteria. If the inclusion of platform motion allows the raising of criterion levels

due to improved student performance, then training effectiveness, at least in the ATD, will have been enhanced.

The crux of the effectiveness issue lies in the transfer of training to actual aircraft, and the retention of trained skills and maintenance of performance levels. If the student takes no skill into the aircraft with him, then the ATD time was wasted. Platform motion systems are assumed to provide a dimension of the flight environment which, due to increased realism of the cues, will enhance transfer of training. Further, it commonly is assumed that skill retention will be enhanced because the skills were learned in a more realistic flight context.

Efficiency of Training

Training efficiency refers to the rate of skill acquisition rather than final performance levels achieved. Operationally, however, it often is the case that efficiency of training can be tied to quantity or quality in that increased rates of learning allow extra training time to expand on what is trained or to raise criterion performance levels to reflect increased proficiency. It must be recognized that none of these values necessarily reflects increased transfer or retention. One assumed value of platform motion is that it enhances acclimation to the flight environment. The time saved in bringing students to acceptable performance levels for beginning inflight training can result in a shorter training program or an increase in productive training time. The former saves money; the latter may lead to improved operational readiness.

The assumption that platform motion enhances the efficiency of training must be objectively measured. Relying on subjective judgements in this area obscures the relationship between rate of skill acquisition, criterion levels achieved, and transfer to the operational setting.

User Acceptance

The instructional value of pilot (user) acceptance comes in two ways. It is important for users to be motivated toward program training objectives and the program as a whole. Acceptance of a device helps provide such motivation. More important, however, is the psychological acceptance of the ATD environment. Such acceptance is assumed to provide a "mental set" through which the student and the instructor respond realistically and enthusiastically in the training situation because they "believe in" its value.

Another aspect of acceptance which is expected to benefit from motion cues is the avoidance of simulator sickness (nausea). This condition is rare, but sometimes occurs when realistic visual cues are presented without the motion cues which normally would accompany them in the real world. Simulator sickness, however, is rare.

Operationally, the assessment of value in this area is difficult. The difficulty arises from a bias in students and instructors in favor of platform motion systems. Inexperienced students prefer the systems due to their novelty, while experienced pilots prefer them because of the relationship between the ATD and what they have experienced in aircraft. As a result, in the absence of quantitative effectiveness and/or efficiency information, the assumption of value in this area represents the weakest upon which to base training decisions.

The assumed instructional values of platform motion systems in terms of effectiveness, efficiency and user acceptance are complex, inter-related and program-specific. The assessment of such values must be undertaken in an on-going manner in any program if the worthiness of including such platforms in future ATDs is to be determined. Any assuption of value is worthless if it never is subtantiated.

CONCEPTUAL TRAINING EFFECTIVENESS FRAMEWORK

This section presents a general conceptual framework intended to aid in determining the need for and training effectiveness of platform motion cuing. A general framework is presented in which two types of platform motion cues are identified: maneuver motion cues; and disturbance motion cues. Additional, mediating factors then are discussed as they impact the training need for motion cuing. They are: motion cue value; motion cue quality; cue redundancy; pilot workload; and aircraft stability.

The section which follows presents available training effectiveness data.

Maneuver and Disturbance Cue Types

One current line of reasoning seems to account for apparently contradictory findings from many studies and experiences dealing with the training value of motion cuing. Motion cues are viewed in two categories: maneuver motion cues; and disturbance motion cues (Gundry, 1976). Maneuver motion is a pilot-initiated, closed loop function. The most important element is that the pilot expects the motion cue feedback; thus, maneuver motion confirms execution and control. It does not necessarily tell the pilot anything new. Disturbance motion, on the other hand, is not pilot initiated. Examples include yaw following engine failure, buffet, turbulence or responses to vehicle instabilities. Disturbance cues provide new information to the pilot, who must react to control the aircraft (or ATD).

Current thinking is that disturbance motion may be important to ATD training, but that maneuver motion may not. Although much of the available evidence supports this viewpoint, there are no relevant transfer of training data to support the assumed importance of disturbance motion cues during ATD training.

Motion Cue Value

The utility to the pilot of stimuli presented by platform motions depends on his ability to correctly interpret and use them, thus making them useful cues. (The difference between stimuli and cues is discussed in Chapter III of the utilization volume). The extent to which platform motion stimuli can become meaningful cues depends on the pilot's experience with related aircraft movements in flight. Many of the transfer of training experiments that have been done comparing motion versus no motion during ATD training have used undergraduate student pilots. These studies have shown no meaningful training benefit from motion cuing during ATD training. One reason may be that only maneuver motion was involved (Caro, 1979). An additional explanation is that students involved in the studies may have had insufficient experience to properly interpret and use the motion stimuli they experienced during ATD training. Further, detailed research seems warranted to investigate the value of motion cues as feedback for improper maneuver performance for undergraduate students. Available evidence and thought is not conclusive on this issue. Research cited by Williges, Roscoe and Williges (1973) suggests that experienced pilots rely more on motion cues, while others conclude that motion cues are more important during initial stages of training (Muckler et al., 1959).

Motion Cue Quality

It is necessary to distinguish between the possible effects of motion systems which are "good" (i.e. are synchronized with other cue sources and are responsive for task requirements) and those which are "poor". It also should be noted that this element must be isolated from the influence of others. For example, it is clear the training of either high or low experience level pilots might benefit from the presentation of disturbance motion cues.

There are potential advantages to be gained from good motion systems for all pilot experience levels. However, for routine maneuver motion there still is the question of how long it takes an inexperienced student to acquire the ability to respond correctly to routine maneuvering requirements in the aircraft. Since in most cases, students fly with instructors initially, there may be little long term training advantage for inexperienced pilots, even using good ATD platform motion cuing. With experienced pilots, the acceptance factor is primary, but there still is the question of whether this factor, alone, should decide the issue.

For a poor motion system, on the other hand, a negative effect could occur for inexperienced pilots. Since they may have inadequate comparison points of reference (i.e. comparison to actual aircraft responses), they may not be able to determine when certain motion cues or visual-vestibular-haptic interactions are appropriate or inappropriate. They may, as a result, learn improper cue-response

relationships if poor motion quality is involved. Experienced pilots have been shown, however, to perform adequately even when fidelity is poor (Bergeron, 1970; and Matheny, Lowes, and Bynum, 1974). Even without motion cues, experienced pilots can perform adequately in ATDs simply by changing their control strategy (Caro, 1977). Program interviews showed that experienced pilots and instructors usually turned motion systems off when motion cues were poor.

Cue Redundancy

The human is a visually oriented organism with respect to job performance. Thus, given a choice among several complementary or redundant sources of information, the pilot will tend to seek out and use visual information first.

ATDs often provide several sources of flight control and feedback information: cockpit displays; out of cockpit visual systems; platform motion; force cuing devices (e.g. G-seats); and sound systems. Considering such cue redundancies, the need for and importance of platform motion cues are determined, in part, by the availability of other cues. It has been suggested that motion cues likely are not necessary for training if other (visual) cues are available (Cyrus, 1978). It has been further suggested that motion cues may help fill an information gap, if adequate visual cues are not available (Irish, et al., 1977). Also, it has been suggested that vestibular (motion) cues may become more important as confidence in available visual cues drops (Williges, Roscoe and Williges, 1973). Resolution of these issues requires further research. However, results of studies showing no training benefit from platform motion cuing may reflect the fact that the training value of motion cues is secondary to visual cues, at least where maneuver motion is involved.

Pilot Workload

Some anecdotal evidence was found suggesting that motion cuing may be necessary for ATD training involving high workload levels which include pilot timesharing between flight control tasks and sensor operation tasks in a high threat environment (Pave Penny training). It is possible in this or other cases that motion cues act as disturbance cues by alerting the pilot to make corrective control inputs. The training value of motion cuing in very high workload situations is an issue requiring further reasearch.

Aircraft Stability

Disturbance motion, which is unexpected, occurs outside of the pilot-aircraft control loop. This control loop is closed, but, more important, the maneuver is initiated by the pilot who in turn receives confirming feedback from ATD motion system responses. When an aircraft is unstable or marginally stable (e.g. V/STOLs, helicopters, or

conventional aircraft with stability augmentation system failures), inputs to the control loop originate from the aircraft itself as well as from the pilot. These imputs demand compensating reactions by the pilot.

The research literature tends to confirm the importance of good motion cuing where training for the control of unstable aircraft is involved. Studies in which the control of relatively unstable aircraft, such as helicopters, was examined (e.g. Mendela, 1970; and Federson; 1962) showed a consistently stronger positive influence for motion on training than did those in which inherently stable aircraft were simulated (e.g. Martin and Wagg, 1978; and Irish and Buckland, 1978). These findings support the view point that motion cues are valuable for training involving the control of aircraft during relatively unstable flight regimes, where disturbance motion is involved.

TRAINING EFFECTIVENESS INFORMATION

Introduction

This section presents results of recent experiments and analyses of the training effectiveness of ATD platform motion cuing. The focus of this section is on transfer of training studies. Studies of performance just in simulators is addressed in a following section titled: In-Simulator Performance. The two are separated because pilot performance differences in simulators may not result in comparable performance differences in flight.

The training effectiveness of platform motion systems is demonstrated by comparing real world performance in an aircraft of a group trained using ATD platform motion cuing and a group trained without such cuing. If the group trained with motion performs better than the no-motion group, a benefit is demonstrated and motion cuing is considered to be of value for training the task under consideration. If there is no difference between the motion and no-motion groups, then no benefit has been demonstrated, and platform motion cuing is considered to be of no meaningful training value. If the motion-trained group actually performs worse than the no-motion group, negative transfer is demonstrated. In such cases, motion cuing actually causes a disruption in inflight performance. Negative transfer, however, is rare in the context of flight simulation. The effectiveness of platform motion cuing also is suggested if such cuing promotes better rates of learning or better performance levels during ATD training (i.e. efficiency).

Available Data

Recent research studies are emphasized in this section. Many of these studies have been criticized for a variety of reasons, including deficiencies in the quality of the motion cues provided (U.S. Air Force Scientific Advisory Board, 1978). Also, many of the simulators used in

these studies have included wide field of view out of cockpit visual systems, which can provide compelling motion cuing information. Finally, the flying training tasks studied all involved maneuver motion rather than disturbance motion. Maneuver and disturbance motion types are discussed in the section of this chapter titled: Conceptual Training Effectiveness Framework. One current line of thinking is that disturbance motion cuing may be beneficial to training, while maneuver motion cuing may not (Gundry, 1976).

A few comments concerning the published literature are in order before reviewing the relevant research. First, studies addressing a particular flying task differ along many dimensions. For example, subject population, simulator used, aircraft involved, training methods used, and scoring techniques often are different from study to study. Unless results are consistent across studies, it is not possible to isolate the critical factors which contribute to or inhibit transfer effectiveness. Second, the published literature often does not fully report all necessary details of the study. Therefore, comparisons among studies are made more difficult.

Also, it seems that researchers, in the quest for experimental control or the need to complete the experiment, sometimes create situations that work to minimize training effectiveness. For example, Jacobs and Roscoe (1975) stated that they did not allow individualized training or "other techniques of training for maximum transfer" in the interest of uniform experimental treatment. Pohlmann and Reed (1978) indicated that "instructing the student... was not attempted because of the limited visual feedback available to the instructor". It should be no surprise that Pohlmann and Reed were not able to demonstrate any transfer in their study.

The methodology used in a training effectiveness experiment is, in many respects, analogous with the instructional methods used in comparable ATD training. It is likely that information which is considerably more meaningful could be obtained in the future if methods and constraints associated with classic laboratory experimentation were abandoned in favor of methodologically sound, but more operationally relevant experimental practices.

Measures of Performance

The studies isolated for review in this section used various measures of inflight performance. Two major classes of measures can be defined: 1) subjective ratings of performance, usually made by flight instructors; and 2) objective measures of performance such as bombing accuracy, final position in air combat, or contacting the boom during air refueling.

Subjective ratings are far and away the most common method of measuring performance in the air because they are the easiest to do.

There is reason to believe, however, that subjective ratings may be unreliable and/or insensitive to significant performance differences. Five studies (Semple, 1974; Payne et al., 1976; Gray and Fuller, 1977; Browning, Ryan and Scott, 1977; and Browning, Ryan and Scott, 1978) *found no transfer using* subjective ratings, but on the same tasks, found substantial positive transfer when objective measures of performance were used. Brictson and Burger (1976), although finding positive transfer for both subjective and objective measures, found substantially higher positive transfer with objective measures. This must be kept in mind when interpreting studies which use only subjective ratings and fail to find differences in inflight performance. The failure may be due to the lack of sensitivity of the measures used rather than ATD fidelity variables involved during ATD training.

Minimum Conditions for Transfer

There are two minimum conditions for transfer: 1) something actually must be learned in the ATD; and 2) whatever is learned must have some application to the inflight task. Therefore, when no transfer performance differences are found, one must ask whether any relevant learning took place in the ATD. As obvious as this may be, studies have been published which indicate that no training in the ATD was attempted, or that although attempted, conditions prevailed which made it difficult or impossible to train the students.

Training Effectiveness Data

Ryan, Scott and Browning (1978) compared approach and landing performance of two groups of transition pilots in the P-3 aircraft following training in Device 2F87F, either with or without platform motion cuing. They found no significant performances differences during inflight tests. Pohlman and Reed (1978) used the Air Force Simulator for Air to Air Combat (SAAC) to investigate the effects of ATD training with and without six DOF motion cuing on air combat performance in the F-4 aircraft. They also found no inflight performance differences as a function of motion cuing during ATD training. However, Pohlman and Reed also point out that "instructing the student . . . was not attempted (in the SAAC) because of the limited visual feedback available to the instructor". Martin and Waag (1978a and 1978b) used the Air Force Advanced Simulator for Pilot Training (ASPT) to examine the influence of six DOF motion for training basic contact, approach and landing, and advanced aerobatics skills for Air Force UPT students. They concluded that significant transfer of training resulted from training in the ASPT, but there were no differences between motion and no-motion trained groups either in the simulator or during inflight performance in the T-37 aircraft.

Gray and Fuller (1977) studied the inflight dive bombing performance of 24 Air Force UPT graduates as a function of three training conditions: training in the ASPT with motion cuing; training in the

ASPT without motion; and inflight training only. Bombing accuracy was measured inflight for three dive bombing angles: 10°, 15° and 30°. Results showed that simulator-trained pilots performed better than pilots trained only in the air (i.e. positive ATD transfer). There were no differences, however, between the motion and no-motion ATD-trained groups.

Hagin (1976) reported two transfer of training studies using the ASPT and the T-37 aircraft. In the first study, eight UPT student pilots without prior T-37 aircraft experience were divided into two ATD training groups, motion and no-motion. Task performance during inflight tests indicated no difference for overhead traffic pattern or takeoff and landing performance as a function of ASPT training with and without motion cuing. In the second study, UPT students received the entire T-37 syllabus either with or without motion cuing in the ASPT, and were subjectively rated using Air Training Command standards during inflight tests. Again, no inflight performance differences were detected between students trained in the ASPT with motion and those trained without motion.

Woodruff and Smith (1974) and Woodruff, Smith, Fuller and Weyer (1976) addressed the issue of platform motion on training efficiency, which was measured as time to reach criterion performance levels. In the first study, two groups of Air Force UPT students were trained in the T-4G (3 DOF) ATD or T-4 fixed-base ATD. ATD training was followed by instrument training in the T-37 aircraft. The two groups showed no differences in flight hours required to reach criterion proficiency during inflight training. The second study used the ASPT and the T-37 aircraft. Eight UPT students in two conditions (motion versus no-motion) were trained. Results indicated no differences between groups in the time to reach criterion performance in either the ASPT or the T-37 aircraft.

The only other mention of efficiency was reported by Jacobs and Roscoe (1975) when they studied motion versus no motion in a GAT-2 (General Aviation Trainer, 2 DOF) device. They presented three groups with no-motion, normal motion, and random motion cues. A fourth group was given only aircraft training. Jacobs and Roscoe reported that only the normal washout motion group "advanced in skill to the practical limit prior to performance in the aircraft". This suggests a faster rate of skill acquistion with motion cuing, at least for beginning student pilots learning basic instrument skills.

The results of Jacobs and Roscoe, however, dealt primarily with the effectiveness of training. Although more efficient, they found no significant differences between motion and no-motion groups in performance in a Piper aircraft during inflight testing. They did, however, find a transfer benefit for all simulator trained students. The most startling finding was in the random, reversed motion group. In this condition motion was in the opposite direction than would be

expected 50% of the time. No subject even mentioned the occurrence. This suggests that it is the leading edge or onset of the motion cue which is most important and not the direction or duration of the motion excursion, at least under the conditions studied.

The findings of Jacobs and Roscoe (1975) support those presented earlier by Koonce (1974). Koonce used three groups (30 subjects each) of multi-engine, instrument rated pilots in no-motion, motion, and aircraft-only training conditions. Simulator training in a GAT-2 device was followed by five instrument and five contact flights in a Piper Aztec aircraft. Results indicated no differences between the motion and no-motion groups. Critics of the study suggest that the use of experienced pilots obscured performance differences because experienced pilots can adapt to and "make the best of" many ATD and flight situations. However, Koonce findings may have meaning for continuation training. Further research is warranted on this and other conditions before well-intentioned but subjective debates can be replaced by substantiated, training-related evidence.

Conclusions

Results of recent transfer of training experiments involving platform motion cuing are consistent with respect to the training value of platform motion cuing. None have demonstrated a need for motion cuing. However, very few studies are available, the quality of the motion cues used in the studies are questioned, recent transfer studies have focused on maneuver rather than disturbance motion cuing, and a number of the studies involved simulations that provide motion cuing through visual systems as well as through platform motion systems.

The U.S. Air Force Scientific Advisory Board (1978) recently reviewed some of these studies, other studies and professional judgements to determine whether it was necessary to keep open the option for motion cuing in tactical fighter simulators (A-10 and F-16 ATDs). Their summary conclusions are presented below because of their current validity based on available transfer of training information.

> "Based on the motion, no motion studies and experiments which have been run to date, a convincing case cannot be made for either including or excluding platform motion in flight simulators for tactical fighters".
>
> "The cues obtained from full field-of-view visual display systems as proposed for tactical fighter simulators are so important that no simulator motion system should be used which compromises the visual display system".
>
> "A four degree-of-freedom motion system (3 angular plus heave) with restricted motion envelope....will not compromise the candidate visual display systems. At the same time such a four

degree-of-freedom system is likely to provide all the potentially useful tactical fighter motion cues attainable by any affordable motion system. In regard to tactical fighter training tasks, there is no rational basis for the performance envelope of the current generation of synergistic six-degree-of-freedom motion systems".

"In the absence of valid, reliable measures of pilot performance, any attempt to assess the effects of training in a simulator on that performance will be unsatisfactory. Such performance measures are in general not presently available, nor is there adequate definition of the air crew tasks based on mission analyses, which is a prerequisite to the development of the performance measures".

IN-SIMULATOR PERFORMANCE

Introduction

This section presents results of recent experiments and analyses of effects of platform motion cuing on pilot behavior in simulators. In-simulator findings are presented separately because pilot performance differences in simulators may not result in comparable peformance differences in flight. In other words, it is a tenuous assumption that performance improvements or decrements observed in ATDs always will mean that comparable performance differences will result in flight. (See the previous section titled: Training Effectiveness Information)

The terms maneuver motion cuing and disturbance motion cuing are used. The terms and their assumed implications for motion cuing in ATDs are discussed in a prior section of this chapter titled: Conceptual Training Effectiveness Framework.

The issue often is raised that maneuver cues may be important during early ATD training as feedback to the student regarding incorrect maneuver performance. This issue is not completely resolved, although much of the available research suggests that motion cuing may not be as important as often assumed for this purpose. The student pilot has many sources of information regarding proper and improper maneuver execution, including cockpit displays and, quite often, out of cockpit visual systems. Given alternative sources of performance feedback to choose from, the human will tend to sample and respond to visual sources.

Recent studies are emphasized in this section. Many of these studies have been criticized for a variety of reasons, including deficiencies in the quality of motion cues provided. However, a number of the stimulators used in the studies also have provided wide field of view out of cockpit visual scenes, which can provide compelling motion cuing information. Finally, several of the studies used highly experienced and skilled instructor pilots as subjects. It has been

shown in other research that experienced pilots tend to perform equally well in differing flight situations by changing the control strategies they use (Caro, 1977). This factor may have been important in several of the studies discussed in this section.

The remainder of this section presents motion cuing findings for the flying training tasks that provided a focus for this program. Findings related to disturbance motion cuing then are presented, followed by discussions of aircrew responses and ATD acceptance factors.

Training Task Differences

This section presents findings on the effects of platform motion on the performance of different flying training tasks in ATDs. Each task is addressed separately. Emphasis is placed on recent research findings; program site visit surveys yielded little relevant information in this particular area.

Aerobatics. Studies found dealing with effects of motion cuing on the performance of aerobatics all involved use of the Air Force Advanced Simulator for Pilot Training (ASPT), which has a six degree of freedom motion system. The quality of the motion cues provided by the ASPT has been questioned. The ASPT also has a wide field of view CIG visual system.

Five ASPT studies found no significant performance differences for basic or advanced aerobatic training as a function of the presence or absence of motion cues. (Waters, Grunzke, Irish and Fuller, 1976; Hagin, 1976; Irish, Grunzke, Gray and Waters, 1977; Irish and Buckland, 1978; and Waag, 1978). Hagin, however, used highly experienced UPT instructor pilots as subjects. Irish and Buckland (1978) also used experienced pilots and the ASPT device. They found that experienced pilots tended to perform better in the ASPT when motion cuing was not used but the visual system was. In the only transfer of training study found that dealt with these tasks, Martin and Waag (1978a) found no difference between motion-trained and fixed base-trained groups of experienced pilots, either during training in the ASPT or subsequently during flight tests. Taken together, these findings suggest that motion cuing may not be necessary for recurrent training in aerobatics in a visually-equipped ATD. However, the question of the quality of the motion cues available in the ASPT when these studies were done makes it difficult to draw strong conclusions.

Spin, Stall and Unusual Attitudes

Only two studies were found which even indirectly addressed this task. Ince, Williges and Roscoe (1975) tested 20 non-pilot volunteers on three flight tasks and four cockpit display types. Results indicated that motion cues seemed to help in disturbed attitude tracking performance, but motion cues did not significantly improve recovery from

unusual attitudes. Instructors interviewed during the program were about evenly divided in their opinions on the need for platform motion for this training application. Hagin (1976) found no difference in pilot performance on slow flight in the ASPT as a function of motion versus no motion. He used experienced pilots, however. Available information is too scant to enable drawing of conclusions for these tasks.

Air to Ground Weapon Delivery. Only one research study has addressed the issue of platform motion for this task (Gray and Fuller, 1977). These researchers conducted a study in which 24 recent graduates of Air Force UPT were divided into three groups of 8 each. Two of the groups received training in the ASPT simulator in bombing at three different dive angles. One simulator group was trained in a fixed base configuration; the second was trained using 6 DOF motion. The third group received training only in the F-5 aircraft. Performance of all three groups was measured in the F-5 aircraft. The study showed significant transfer of training for both simulator-trained groups. However, there was no indication of any training benefit from the use of motion during ATD training or subsequently in flight.

Rivers and Van Arsdell (1977) reported on the Air Force simulator comparative evaluation study, in which teams of pilots flew and subjectively compared the performance of several dozen different ATDs. Their conclusion was that motion cues were not necessary for the training of air to ground weapons delivery. They went further to recommend that ATDs used for this training should be equipped with well designed visual systems and G-suit/G-seat devices rather than platform motion systems. No data exist, however, to substantiate their subjective conclusions.

Some anecdotal evidence was found during program surveys suggesting that motion cuing may be necessary for ATD training involving high workload levels which include pilot timesharing between flight control tasks and sensor operation tasks in a high threat weapon delivery environment (Pave Penny training). It is possible in this or other similar cases that motion cues act as disturbance cues by alerting the pilot to make corrective control inputs. The training value of motion cuing in very high workload situations is an issue requiring further research.

One experiment, one survey and one interview do not make for conclusive proof. If the conceptual training effectiveness framework used in this chapter is reasonably valid, one would expect that the value of ATD motion cuing for air to ground weapons delivery would be minimal, except where disturbance cues may be important for task performance in the ATD.

Terrain Following/Terrain Avoidance. This is another task where little research has been performed to date. Besco (1961) found that

motion seemed to facilitate precise tracking performance during low-level terrain following flight. However, only one axis (pitch) was used, and an out of cockpit visual system was not used. A more recent study by Parish, Honck, and Martin (1977) showed that pilots conducting visual slalom runs in a helicopter simulation preferred motion. However, objective measures of performance reflected no advantage to having it. Their results did show reduced control activity when motion was present, however, suggesting the use of different control strategies when motion cues are present. Such a result would support subjective preferences for high quality motion cues in ATDs.

Several pilots who were interviewed during the STRES program mentioned that motion cues may be desirable during automatically controlled terrain avoidance or terrain following flight to alert crewmembers to flight path changes when they are occupied with other tasks. Because of its altering value, motion may be desirable for low level flight training in ATDs. Its actual value, however, should be based on empirical tests. Such tests have not been done.

Air To Air Combat. Only one study was found that directly addressed effects of platform motion on performance of air combat tasks in an ATD. (Pohlmann and Reed, 1978). Using the Air Force Simulator for Air to Air Combat (SAAC), they found no performance differences in the device or subsequently in the air for transitioning pilots. However, they also point out that instruction in the ATD was not attempted because of limited visual feedback to the instructor. Also, motion cues quality produced by SAAC has been questioned. The SAAC platform motion system is not used during TAC ACES continuation training in the device.

The U.S. Air Force Scientific Advisory Board (1978) recently reviewed available research studies and combined the findings with professional judgements to determine whether it was necessary to keep open the option for motion cuing in tactical fighter simulators (A-10 and F-16 ATDs). One of their conclusions was that, based on the motion, no-motion studies and experiments completed when they made their review, a convincing case could not be made for either including or excluding platform motion in flight simulators for tactical fighters. They also concluded that a four DOF motion system (three angular plus heave) with a restricted motion envelope likely would provide all the potentially useful tactical fighter motion cues attainable through any affordable motion system.

Further research is needed on motion cuing for air to air combat. Requirements for both maneuver and disturbance (e.g. buffet) cuing should be carefully considered, and the research should be focused specifically on these potential cue requirement issues. Potential needs for force cuing using devices such as G-suits, G-seats, helmet loaders and similar devices also should be considered in future research. (See Chapter VI of this report: Force Cuing Devices)

Takeoff and Landing. Research investigating the effects of motion for training these tasks contains mixed findings, and the studies deal only with individual takeoff and landing. Earlier research in carrier landings (Ruocco, Vitale, and Benfair, 1965) and night landings with a crosswind (Wendt, Stark, Simon, and Cohen, 1961) reported positive benefits from the incorporation of motion cues in the ATD. It should be noted, however, that both studies involved an additional factor. Both the crosswind and the movement of a carrier deck represent a compensatory control task for the pilot in which motion cues might be expected to help. More recent studies (Waters, Grunzke, Irish and Fuller, 1976; Hagin, 1976; and Irish, Grunzke, Gray and Waters, 1977) report no benefit from motion in the ASPT for either takeoff and landing or GCA tasks. Further, Martin and Waag (1978a), in a transfer of training study, found no benefit from motion cuing.

Formation Flight. There has not been a great deal of research in this area either. While Brown and Johnson (1959) found that pitch axis motion was not important for formation flight, Brown, Johnson and Mungell (1960) reported that three DOF motion (roll, pitch and yaw) enchanced precision of formation flight tracking. Woodruff, Smith, Fuller and Weyer (1976) found no benefit from motion for this same task using the ASPT. Available research is not conclusive. However, close formation flight, for example, is a very visually-oriented task. To the extent that only maneuver motion is involved, platform motion cuing likely is of little impact on in-simulator performance.

Air Refueling. No research was found relating directly to this task. Findings from studies involving formation flight obviously have some relevance, because air refueling involves close formation flight. The value of prompt, accurate motion cues in an ATD used for refueling training remains an unresolved issue, particularly with respect to the disturbance cuing value of motion for maintaining precision control and contact with the tanker.

Disturbance Cuing

A large part of the in-simulator research deals with effects of disturbance motion. A primary reason in developing ATDs initially was to increase safety in training certain pilot response capabilities. In-simulator research has involved work in emergency response, turbulence, and the handling of unstable aircraft. Overall, results of these studies indicate an advantage to including motion cues in the training device. As mentioned previously in the conceptual framework section of this chapter, many studies have concluded that motion cuing assists pilots in learning to handle relatively unstable aircraft, such as V/STOLs and helicopters. In fact, various training specialists have pointed out with respect to training how to control pilot induced oscillations, motion cues may be required in the ATD in order to create the training situation.

Research dealing with flight control in turbulence has produced fairly consistent results. Studies by many researchers (Peny and Neish, 1964; Wendt, Stark, Simon, and Cohen, 1961; Ruocco, Vitale, and Benfari, 1965; Borlace, 1967) have reported improved flight control performance in ATDs under turbulent conditions when platform motion cues are present.

The many studies conducted on emergency response training have led to one conclusion. The presence of motion is beneficial in learning to detect and handle certain emergency situations in the ATD. Young (1967) reported that recovery times for instrument landing system failures were 100% longer without motion than with motion. Cohen (1970) found that without motion, response time to activate emergency brakes during a brake system failure was two to four times as long without motion cues.

Much of the emergency response work has dealt with engine failure training. These studies consistently report advantages to motion in the ATD (Cooper, 1963; Spitzer and Rumsey, 1966; Gerathewohl, 1969; DeBerg, McFarland and Showalter, 1976). In the study conducted by DeBerg et al., the group trained with motion <u>and</u> visual cues performed best in responding to outboard engine failures in a simulated KC-135 aircraft. The motion-only group performed better than the no-motion group.

Operationally, this type of task training appears to derive the greatest benefit by far from the incorporation of platform motion cues or similar cue forms.

<u>Aircrew Responses</u>

Research also has dealt with the design and readability of cockpit instruments under conditions of motion and no motion. Several studies reported that displays and controls which were judged superior in fixed-base ATDs were, in fact, judged inferior in both moving base simulators and actual flight. Ince, Williges, and Roscoe (1975) concluded that the order of merit for experimental flight displays evaluated in a simulator corresponded more closely to their order of merit in flight when platform motion cues were present in the simulator. This confirmed the results found by Jacobs, Williges and Roscoe (1973) showing that azimuth steering on eight control displays (4 compensatory and 4 pursuit) improved under conditions of simulator motion. Stark and Wilson (1973) related motion to the question of aircraft control and instrument use. They concluded that motion in six degrees of freedom, as well as visual cues, were needed to allow adequate control handling without excessive instrument use by the pilot. This conclusion was not addressed in the other literature examined, and seems to be an overstatement of ATD requirements based upon this one aspect of flight training.

The study by Stark and Wilson suggests another area in which motion research has been conducted, namely tracking performance and control

handling. Douvillier, Turner, Mclean, and Heinle (1960) reported that tracking task performance in a motion equipped simulator more closely resembled actual flight tracking than did performance without motion cuing. Subsequent studies have tended to support this conclusion (e.g. Van Gool, 1978). Studies also have shown pilot control strategies to be more similar to actual aircraft control strategies when motion cues are present (e.g. Huddleston and Rolfe, 1971; and Matheny, Lowes and Bynum, 1974). It should be pointed out that although these differences between control handling and tracking in motion-based versus fixed-base ATDs seem strong, no one really has determined whether the differences have any practical training meaning in flight situations involving maneuver motion (as opposed to disturbance motion).

A few studies have at least indirectly approached the issue of how many degrees of freedom (i.e. axes of motion) are needed in training simulators. The question has never been approached in a comprehensive way or with respect to specific training requirements. This is partly due to the task specific nature of motion cues. Bergeron (1970) examined the effects of motion in one and two-axis closed-loop tracking tasks. He reported that motion had little or no effect on control of single-axis tasks, but it did enhance performance on two-axis tracking. The ASPT studies (Waters, et al. 1976; and Irish, et al. 1977) concluded that not only were 3 and 6 degrees of freedom for basic tasks inferior to no motion, but they were overall not significantly different from one another. This question will require more research before confident conclusions can be made for specific training applications.

Device Acceptance

This area deals with the enhancement of pilot acceptance and motivation in the use of ATDs. Caro, Jolley, Isley, and Wright (1972) pointed out that the increased realism offered by motion cues increases the motivation of users. They went on to suggest that motion cues must be even more faithfully reproduced for experienced pilots who have learned to attend to certain subtle cues in the actual aircraft. Parish et al. (1977), in a study of helicopter slalom runs, reported that although objective performance results showed no appreciable performance advantage because of platform motion cues, pilots subjectively preferred motion. Interviews with pilots during the STRES program confirmed a strong preference for platform motion so long as the cues provided were not incorrect and misleading. Several researchers (Clark and Stewart, 1973; Stark and Wilson, 1973; and Puig, Harris and Ricard, 1978) point out that motion may inhibit simulator sickness. This is one physiological reaction to poor visual-vestibular interaction which occurs most often when visual but not motion cues are available in the ATD environment. It almost certainly lowers the acceptance of such an ATD. No mention is made however, as to the degree of motion fidelity required to offset this condition. It is possible that very modest motion cues would prove adequate. Also, simulator sickness is a relatively rare phenomenon.

CONCLUSIONS

Definitive conclusions are difficult to draw regarding the training values of platform motion cuing, in spite of the rather extensive research that has been done and the information gathered during program site visits. This is due partly to the fact that a conceptual training effectiveness framework for interpreting possible values of platform motion cuing only recently has been proposed, and because much of the recent, potentially relevant research has involved the use of simulators with motion systems that have been questioned in terms of the validity of cues provided. The following conclusions must be tempered by these considerations. They should be considered as hypotheses rather than conclusions; as such, they should be subjected to further test before concrete design decisions are drawn.

The need (or lack of need) for platform motion cuing should be decided on the bases of the contribution of such cuing to training efficiency and effectiveness. Motion cuing for the sake of "realism" is not the issue.

Cuing is a hierarchical consideration. Visual cuing is highest on the scale of preferred cues. Motion cues may provide either complementary or supplementary cues, but their value in relation to visual cues cannot be quantified presently. Based on available research, motion cues, in the presence of adequate visual system cues, are secondary.

Available in-simulator evidence suggests that incorporating platform motion cues facilitates problem recognition, at least for certain problems such as engine failure in multi-engine transport-type aircraft. However, no transfer of training data are available to support or refute the training effectiveness of this use of motion cuing.

There is no evidence to suggest that six degrees of freedom of motion cuing is necessary in ATDs. Available evidence suggests that the need for a particular axis of cuing should be determined on the basis of the cue's known or anticipated contribution to the achievement of precisely stated training objectives. Alternatives to platform motion systems (such as various force cuing devices) should be examined as alternative cue sources.

It has been shown experimentally that fixed-base simulations result in pilot control patterns that are different from those measured in motion-base simulations. However, there is no evidence that negative transfer results from fixed-base training, or that positive transfer of these skills results from motion-based training.

The need for motion cuing during continuation training is unclear. This includes both maneuver and disturbance cuing. It is possible that verbal instruction and pilot experience will obviate the need for motion

cuing during continuation training, although this possibility also remains to be demonstrated.

There is little evidence to support the contention that platform motion cuing enhances efficiency of training in an ATD. Studies addressing rates of learning and final levels of obtained proficiency show mixed results.

There is little question that pilots prefer ATDs that provide valid platform motion cues. However, pilots often cannot tell when motion systems are on or off. This includes transport and fighter aircraft simulations, and usually involves the presence of out of cockpit visual cues.

CHAPTER VI

FORCE CUING DEVICES

SUMMARY

Force cuing devices include G-seats, G-suits, seat shakers, helmet loaders, arm loaders and visual greyout/blackout capabilities. These devices sometimes are referred to as "G-cuing" devices. The common assumption is that incorporating such devices into ATDs will enhance training because they may provide further realism in the ATD training environment. No evidence exists, however, on whether force cuing devices enhance either the efficiency or effectiveness of ATD training. This is because the devices are relatively new and untried. It is possible that advanced G-seats and related force cuing devices may prove to be workable alternatives to platform motion systems for disturbance motion cuing; this possibility also remains undemonstrated. Force cuing devices involve both onset and prolonged maneuver cues; therefore, the cues they provide should be correlated to and synchronized with other maneuvering cues provided by cockpit displays, platform motion systems and out of cockpit visual systems.

FORCE CUING DEVICES

Force cuing devices include a broad spectrum of mechanisms intended to increase the range and realism of cues in the simulated flight environment. These devices include: G-seats; G-suits; seat shaker and buffet devices; helmet loaders; arm loaders; and visual greyout/blackout systems.

Force cuing devices are intended to reproduce two general classes of cues found in flight: 1) sustained acceleration/deceleration cues (longitudinal, lateral, vertical and rotational); and 2) flight situation cues (buffet, rough air/turbulence, and runway rumble).

The cues are intended to influence the pilot by supplying sensory information concerning flight conditions such as acceleration magnitude and direction. Force cuing devices attempt to reproduce these cues by artificially inducing psychological and physiological system responses to biomechanical events which would occur in flight.

In the development of force cuing devices, there have been three notable trends within the last decade: 1) Devices, such as G-seats, have been modified continually in attempts to improve the realism of the cues produced while minimizing the distraction caused by the cue production mechanics; 2) Development of newer individual devices has centered on simulation of more specific cues, such as visual blackout and limb heaviness; 3) Development of integrated devices, such as ALCOGS, (Advanced Low Cost G-cuing System) has been pursued to lower the cost of force cuing devices, to provide at least some motion onset cuing, and to

combine several cuing systems into a single device which is more comparable with actual flight (Albery, Gum and Kron, 1978).

RELATED FIDELITY FEATURES

A review of the literature and information gathered from program site visits indicates that force cuing devices are related to two other simulator fidelity features: platform motion systems; and out of cockpit visual systems.

Force cuing devices and platform motion systems both produce motion-related cues. However, there are differences between these systems. Platform motion systems are mechanically more complex. Platform motion systems typically provide only motion onset cues, which represent just the leading edge of acceleration effects. (An obvious exception is the fact that platform motion systems almost always provide sustained cuing in the pitch axis during coordinated flight, and can provide sustained roll axis cues during uncoordinated flight, which is common in rotary-wing aircraft and in uncoordinated flight in fixed-wing aircraft). Thus, in most cases, platform motion system cues stimulate vestibular (inner ear) motion and acceleration sensors, while force cuing devices typically influence haptic (skin/muscle) sensors in the body.

The relationship between force cuing devices and platform systems can be viewed in two ways: complementary and substitutional. The contrasting natures of the two motion systems may complement one another when combined. (See Chapter VII of this volume for cue synchronization.) Such a combination could provide a broader range of cuing capabilities (Taylor, Gerber and Allen, 1969; Stark and Wilson, 1973). Combinations of onset, sustained and flight situational cues may be more realistic to the actual flight environment.

If motion cuing is required at all for training (see Chapter V of this volume), force cuing devices offer interesting alternatives to platform motion system cuing. In other words, it is possible (although unproven) that force cuing devices, such as advanced G-seat systems, may be capable of providing acceleration motion cuing and that platform motion systems may not be required for some applications as a result. Realizing this, at least one military organization (Tactical Air Command, SIM-SPO Briefing, 1977) has suggested using force cuing devices in lieu of platform motion systems. Again, it must be noted that the substitution of force cuing devices may be an attractive mechanical and cost alternative to platform motion cuing, but evidence on the training practicality or acceptance of this substitution is largely lacking.

The relationship between force cuing devices and out of cockpit visual systems seems to be complementary. Motion cues and visual cues often afford redundant information, allowing the pilot to "feel" the aircraft movement as well as to "see" changes relative to the simulated

flight environment (see Chapter III of this volume). Several researchers, including Stark and Wilson (1973), have reported that realistic reproduction of visual flight imagery without accompanying motion cues sometimes results in vertigo. Further, unrealistic and sometimes conflicting motion cues can result when ATD systems cannot respond rapidly enough to minimize lag time between motion and visual cues, as when platform motion is coupled with the highly dynamic visual imagery of high speed tactical flight. It has been suggested, although unproven, that the same devices may complement visual systems under less than optimal conditions by providing cues which "fill-in" information lost due to restricted visual system fields of view (Irish, et al., 1977). Albery, Gum and Kron (1978) have suggested designing a number of experiments to test the suggestion that G-suit/G-seat systems alone might provide sufficient simulated motion cues if coupled with a high-fidelity, wide field of view visual system.

Operationally, these relationships suggest decision points regarding the training potential of force cuing devices. Decisions to incorporate (or not incorporate) force cuing devices as complements or supplements to platform motion or visual system cuing should be made on the basis of an analysis of task requirements, at least initially. The results of systematic investigations of the training value of force cuing then should be used to refine future design and use issues. Presently, there is virtually no relevant research or operational experience to draw upon.

The combination of force cuing devices with a visual system involves several decision points. If the training task is highly visual, then motion cues may not be as important. If the task is not visual, (e.g. instrument flight) or the visual system is restricted, (i.e. narrow field of view), then motion cues may become more important in filling information gaps regarding aircraft responses. This role of platform motion remains unclear, however (see Chapter V of this report). One operational implication does seem clear. If force cuing devices are combined with a visual system, the integration must keep lags between visual and motion cues to a minimum; otherwise the cues may be more harmful than helpful (see Chapter VII of this report).

ASSUMED INSTRUCTIONAL VALUES

One measure for assessing the "value" of any training device is in terms of its training utility, substantiated through research or actual use, and matched against the expectations and requirements which initially prompted the design. Force cuing devices are being developed with the expectation that they will provide valuable benefits to ATD training. The literature identifies potential benefits in the following areas: 1) training (effectiveness, efficiency, and acclimation); 2) pilot acceptance (realism, and avoidance of simulator sickness); and 3) cost-benefit (substitution for platform motion).

In examining each of these potential benefits, increasing the effectiveness of training is the most important benefit expected from the incorporation of force cuing devices in ATD design. The amount of training transferred to the aircraft represents the value of that training. Any increase in the amount or quality of transfer constitutes an increase in training effectiveness.

Time spent in training reflects costs not only in monetary terms but in the capacity of the system to produce trained personnel. One measure of training efficiency is the amount of time necessary to train individuals to meet predetermined skill criteria. The faster such criteria can be met, the more efficient the system is in providing training. If the addition of force cues increases the learning rate, thereby decreasing the time required for a pilot to move along the learning curve toward criterion performance levels, then more pilots can be trained per unit of time, and the cost of training per pilot drops, at least theoretically.

Pilots in ATD's experience an initial period of acclimation in which familiarization with the simulator occurs. During this period the novelty of the ATD environment wears off, and they "learn" about the ATD. As pilots acclimate to the ATD, their initial performance stabilizes. This stabilization indicates that the point has been reached where the novelty of the training environment no longer influences the rate at which the individual moves along the learning curve. When the pilot is acclimated, the increase in skill toward a criterion performance level can be reliably assessed. If the incorporation of G-cues or flight situation cues enhances acclimation, then the average training period might be shortened.

Pilot acceptance of ATDs is important to their willingness to use the device and, subsequently, to the effectiveness of the training. A realistic reproduction of flight motion in the ATD may increase acceptance by making the simulation seem more "real". Force cuing devices reproduce some characteristics of actual flight cues which cannot currently be produced in any other way (Stark and Wilson, 1973; Albery et al., 1978). If force cue generation increases realism and acceptance, instructors and students may be more willing to use ATD's. Such an attitude is important to performance.

Some pilots have experienced nausea or dizziness when presented with realistic, wide angle visual flight scenes without experiencing the motion cues that normally accompany visual cues in the operational environment (see Chapter VII of this report). The introduction of motion cues compatible with the visual cues produced in the ATD might serve to lessen the occurrence of these symptoms and remove this negative experience for the few students who experience it (Puig, et al., 1978). As previously stated, the operational issue is not simply the presence or absence of the motion cues but also the synchronization between the visual and motion cues.

FORCE CUING LIMITATIONS

While there are potential training values associated with force cuing devices, there also are limitations to their effect. The most basic limitation is that body weight on the ground never exceeds 1 G under most circumstances. Because of this, any change in force loading on various parts of the body must occur as a result of changes in body attitude or variations in the shape of the flesh-supporting surface. Thus, when a G-load condition is simulated, the shape of a G-seat may change (i.e. inflate or deflate to allow more or less surface contact), but the student never experiences "weightlessness" or "body sag". Kron, Young and Albery (1977) point out that many visceral effects, such as rib-cage shifts or lacrimation (body fluid) flow, and inertial load build-ups experienced by the body are beyond present technology to achieve in ATDs. The need to do so in ground based training also is in question.

A second limitation involves the use of associative cues such as those provided by greyout/blackout visual features and G-suits. These devices create a cue which the pilot "associates" with an acceleration condition, i.e., G-loading. The value of these ATD cues is limited by the strength of association experienced by a given individual. In other words, the student may require some experience in flight in order to know precisely what the ATD cue means.

TRAINING TASK DIFFERENCES

The use of force cuing to train specific tasks points up the specific cuing nature of these devices as it relates to task requirements. The use of force cuing devices is expected to be of value in those training tasks representing more dynamic and variable flight patterns. These tasks include:

Aerobatics;

Spin, stall, and unusual attitude recognition; prevention and recovery; and

Low-level terrain following flight.

The potential value of force cuing in these tasks is the addition of haptic cues (i.e. skin/muscle cues) to control the aircraft during rapidly changing flight profiles. Further, in the case of low-level terrain following flight and air to air combat, pilots often have other tasks which occupy their attention. These tasks could, for example, involve map reading, sensor operation or radar interpretation. In task situations where visual cues cannot be fully used, other cues, such as force and motion cues, may become more important.

The value of force cuing devices may not be as great for other flight tasks such as:

Individual and formation takeoff and landing;

Close formation flight and trail formation, both close and extended;

Air-refueling; and

Air-to-ground weapon delivery.

The reason is that such tasks do not involve the rapid flight profile changes of the tasks previously cited. If performed correctly, they involve far less G-loading. Exceptions to this are roll-in and pull-out phases of some weapon delivery tasks. However, even these do not represent unexpected or erratic changes in aircraft states.

Operationally, assumed instructional values are key to inclusion of force cuing devices into any ATD. Although such values still are only assumed and not conclusively proven, force cuing devices should be considered if ATD program criteria are not being met in the task areas mentioned. Such consideration is especially valid when the tasks being trained fall into the first group of training tasks.

CONCEPTUAL TRAINING EFFECTIVENESS FRAMEWORK

One current line of reasoning seems to account for apparently contradictory findings from many studies and experiences dealing with the training value of motion cuing. Motion cues are viewed in two categories: maneuver motion cues; and disturbance motion cues. Maneuver motion is a pilot-initiated, closed loop function. The most important element is that the pilot expects the motion cue feedback; thus, maneuver motion confirms execution and control. It does not necessarily tell the pilot anything new. Disturbance motion, on the other hand, is not pilot initiated. Examples include yaw following engine failure, buffet, turbulence or responses to vehicle instabilities. Disturbance cues provide new information to the pilot, who must react to control the aircraft.

Current thinking is that disturbance motion may be important to ATD training, but that maneuver motion may not. Although much of the available evidence supports this viewpoint, there are no relevant transfer of training data to support the assumed importance of disturbance motion cues during ATD training. Also, evidence has only recently become available addressing the issue of whether out of cockpit visual systems can provide adequate maneuver and disturbance cues for training purposes. It is possible that platform motion or force cues may contribute little to training in the presence of adequate visual system cues, but the evidence is incomplete. This issue is addressed in

more detail in Chapter V of this volume in the section titled Conceptual Training Effectiveness Framework.

INDIVIDUAL FORCE CUING DEVICES

Several force cuing devices are discussed in the following paragraphs. The devices were chosen because they currently are in use on operational and/or research ATD's or they represent concepts "on the drawing board" to be designed in the near future. Each device is described and examined regarding potential training issues, research results and conclusions which can be drawn concerning the training value of the device.

G-Seats

The G-seat was the first force cuing device to be developed (Dynaseat-Goodyear Aerospace Corp., 1967). While resembling an aircraft cockpit seat, it was designed to produce the stimuli associated with flight-induced body G-loading.

G-seats developed over the last decade have functioned according to relatively consistent design principles. A series of pneumatic bladders located in the seat-pan and back rest inflate and deflate according to computer instructions to change the seat configuration with respect to attitude, elevation and shape. The bladders, working in concert with a tension lap belt and in some instances thigh cushions, were investigated for their potential to simulate sustained and onset cues which occur under G-conditions, such as skeletal attitude changes, head/neck bobbing, flesh scrubbing, flesh/seat contact changes, and localized flesh pressure changes (Kron et al., 1977). The simulation of such cues partially reproduces acceleration effects on the body which occur in actual flight.

Several training issues arise as a function of G-seat cuing capabilities. One of the issues is whether G-seats actually add realism to simulation and whether, as a result of the presumed realism, any additional effectiveness or efficiency is evidenced in training. A second training issue is cost-benefit. This involves the ability or inability of G-seats to supplement, complement or replace more costly platform motion systems. This is still a research issue and involves a great deal of discussion between proponents, (e.g. Kron et al., 1977; Gray and Fuller, 1977) and opponents (e.g. USAF SIM-SPO, 1977). Other parties to the discussion, such as Tactical Air Command, have left the decision open. Although decisions regarding inclusion/exclusion ultimately may not be made at the operational level, acknowledgement of the controversy is important.

G-seats have received more research attention than other force cuing devices. There are also more G-seats in operational and research ATD's than are other force cuing devices (approximately 6-7). Even so, there

is little research information available for several reasons. Little research has been performed on the G-seat alone. The seats usually are activated in conjunction with other subsystems, thus obscuring results directly attributable to the seats. None of the devices are exactly alike. In the thirteen years since G-seats were introduced there have been several technological advances. Each generation has slightly different design and performance characteristics. Further, none of the devices has been designed with specific training objectives in mind. However, this is not uncommon during early technology development periods. The net effect is that very little is known about the design or use of G-seats for training.

Of the research available, the areas of realism and in-simulator crew performance have received the most attention. Increased realism was evaluated by Barrett et al. (1969). They asked blindfolded private pilots to identify maneuvers in a simulator equipped with the G-seat. With the functional G-seat, subjects rated realism 30 percent higher (on a scale of 0-100) than without the seat. Irish and Brown (1978) also reported improved subjective ratings of realism in research conducted using the Simulator for Air-to-Air Combat (SAAC). Both highly experienced and less experienced pilots took part in the study. Six maneuvers were flown: fighting wing, barrel roll attack, sequential attack, free engagement, aileron roll and loop. Results indicated higher ratings of realism for both pilot groups using the G-seat on all except the aileron roll.

Although there have been no recent studies on transfer of training to actual aircraft, there have been several studies evaluating in-simulator performance involving G-seats. Two have been reported (Irish, et al., 1977; and Irish and Buckland, 1978). In these studies, a number of flight performance measures were taken on several tasks flown in a simulated T-37 aircraft by experienced pilots under varying conditions of turbulence, visibility and other environmental factors. Measures were taken with the G-seat on and off. Results of the first study revealed that the G-seat was influential in improving control handling under adverse conditions. However, this conclusion was not borne out in the second study, thus pre-empting any reliable conclusions which might have been drawn from these two studies.

There have been other studies indicating improved control handling using an active G-seat. Kron, as early as 1970, (Kron et al., 1977) reported that control handling improved using a G-seat. This was further quantified by Ashworth, McKissick and Martin (1977) in research conducted in the NASA Langley Differential Maneuvering Simulator. Results indicated that of all flight control measures taken during air-to-air combat flights, 90 percent of those showing increased control precision did so when the G-seat was activated. The results also specified that improvement was greatest for lateral control of the aircraft during the transition phases of the task.

Overall, the scarcity of research undertaken using existing G-seats limits any attempt to draw reliable conclusions regarding the training value of these devices. While it does appear that G-seats may provide meaningful cues to pilots of varying experience levels, their effectiveness may be mediated by task characteristics and pilot experience. There is no valid evidence that training effectiveness or efficiency are improved by cues emanating from G-seats.

G-suits

G-suits normally are employed in tactical aircraft flight to counteract blood pooling in lower body extremities and resultant brain and retinal starvation during high-G conditions. Pilots apparently associate the tactile perception of pressure induced by the G-suit with high-G conditions (Kron et al., 1977). If this association is valid, it makes possible meaningful G-suit cuing in ATDs.

Since G-suits, (or anti-G-suits) are used in actual flight, their inclusion in ATD's potentially adds to the tactile realism of the simulation. Beyond this additional realism, there is little evidence that training effectiveness or efficiency increases as a result of G-suit cues. A major training issue arises due to the associative nature of the cue since the strength of the cue may be a function of the pilot's experience and, thus, his ability to make the association. In other words, the cues provided by G-suits may be mediated by experience levels. In operational practice, the use of G-suits in ATD's varies widely, which suggests that any perceived benefit is not strong.

No training effectiveness or efficiency conclusions can be drawn with respect to the use of G-suits in ATDs. The assumption that G-suits provide meaningful realism in ATDs must be questioned because the devices often are not used in fighter aircraft ATDs. If they were judged important, they would be used. On the other hand, their importance may be overlooked. Also, the issue must be raised regarding the amount of inflight experience a pilot must have in high-G environments in order to be able to correctly interpret and use G-cues provided by G-suits in an ATD. Finally, the issue of G-suit pressure scaling has not been addressed for ATD applications. It is assumed that G-suit pressures experienced in flight should be faithfully reproduced in ATDs. However, ATDs provide, essentially, 1-G environments which lack other vestibular and haptic force cues. Since motion and force cues are interrelated neurologically, the issue of how to properly scale and interrelate all cues in a 1-G environment must be addressed. Research has not addressed this, to date.

Seat Shaker/Buffet Devices

Seat shaker/buffet devices are programmable vibrating mechanisms that can shake the seat, control stick or pedals of the ATD. These force cuing devices reproduce flight situation cues which are

somatically monitored by the pilot (i.e. sensed by feel of the body). Cues such as runway bump, turbulence and buffet can be simulated using these devices.

A primary issue for training is whether the incorporation of these systems provides any increase in training effectiveness or efficiency. Further, even if increases are produced, are they significant or do they represent conditional acclimation to flight situations (e.g., turbulence) which would occur anyway during normal transition to the aircraft?

No empirical research was found that examined the possible benefit that might be gained by including these devices in training simulators. Their inclusion seems to be based upon the increased realism they may provide and the presumption of benefit as a function of that realism. However, seat shakers, for example, may produce useful stall-onset cues. The lack of empirical research or operational experience precludes the drawing of any reliable conclusions regarding the training value of seat shaker/buffet systems. Within the conceptual training effectiveness framework, mediating influences could exist from any of the elements proposed; however, none have been evidenced in the available research.

Helmet Loader

Helmet loaders are designed to simulate the helmet/head weight increase which occurs under positive G-loading conditions. Such an increase results in compression of the spine and loss of lateral head control by the pilot in the actual flight situation.

The primary training issues involve presumed values of the helmet loader effectiveness and efficiency. Further, as with the previous buffet device, are the cues created by the helmet loader required throughout training as a fixed feature or can acclimation occur during normal transition to the aircraft without increasing the time required for such transition?

Another issue which has arisen as a result of the potential danger in mechanically compressing the spine is one of scaling. Scaling refers to the maintaining of characteristic relationships between acceleration and G-load while lowering the amount of G-load being placed on the body. The issue addressed is whether realistic G-load levels are necessary or desirable in the ATD environment. To date, no research has been conducted to answer this question. Just as the production of onset motion cues with washout belies the needs for full range physical displacement, it may be that only a fraction of the G-load experienced under actual flight might be needed to provide adequate cues to enhance training. The basic issues are the roles and values of force cues in ATD training. These issues remain to be resolved.

A prototype helmet loader has been developed and studied at NASA (Ashworth and McKissick, 1978). Initial testing of the device revealed significant positive effects of the helmet loader on pilot performance in an aerodynamically limited research simulator. Using highly experienced pilots flying air to air combat, Ashworth and McKissick found a 50% reduction in the variability of control handling with the experimental helmet loader. The lower variability was primarily in longitudinal measures involving pitch attitude. The indications were that greater precision was experienced in control of the aircraft when the helmet loader was operative. Further, the pilots reported increased realism in the simulator with the additional cues provided by the device.

While the helmet loader does seem to reproduce realistic cues, there are few reliable conclusions which can be drawn at this time. The utility of helmet loading cues may depend upon the experience level of the pilot and his ability to relate the cues to actual flight conditions. Further, the utility of the cue may be a function of task characteristics and the presence of other, overlapping information sources, such as G-suits and G-seats. In other words, the value of helmet loaders for training is unknown.

<u>Visual Greyout/Blackout</u>

This represents the strongest example of the relationship of the visual system to force cuing devices. Under high G-load conditions, pooling of blood to the lower extremities of the body occurs. As a result of this, blood flows initially from the vessels of the eye, and second from the brain itself. The initial effect is the blurring or graying out of the visual field. Tunnel vision occurs as the periphery of the visual field narrows. Eventually blackout occurs as a result of oxygen starvation of the brain. Visual system greyout/blackout simulates the perception of this force cue. Pilots are assumed to associate these changes in ATD visual imagery with high G-load conditions during flight.

Training issues regarding greyout/blackout techniques center on the effectiveness of the association between changes in the visual scene and G-load conditions. Many physiological effects are involved when greyout/blackout occur in flight environment. It is a fair question to ask, therefore, whether the association even is made and, if so, whether it is productive for training in ATDs. Such an association might also be mediated by the experience level of the pilot. As with other force cuing devices, the issue of training benefit versus training exposure is a valid one. The question remains, is it necessary to build such a feature into the simulator or can exposure during actual training flights suffice?

No research was found that addressed these issues or evaluated the training value of the greyout/blackout feature. Review of the feature

in the SAAC simulator revealed that unrealistic recovery times for the greyout/blackout system allowed "simulator-wise" pilots to beat the system during simulation flights, or to use the inadequacies of the feature to their own advantage. For example, pushing the stick forward to reduce G-force results in a very rapid "recovery" of the simulator's visual system, making the adversary again visible. The human visual system does not recover as rapidly. Therefore, "simulator wise" pilots learn to take advantage of a simulator inadequacy. The training value of doing so is highly questionable, especially for skilled fighter pilots who are "taking advantage" of the situation. However, allowing transitioning fighter pilots to "see what happens" during blackout, using this method, is an issue worth investigating. There may be an undiscovered value in this low realism characteristic of SAAC.

There are few conclusions which can be made regarding the visual greyout/blackout feature since no research performed to date has specifically focused on this feature. As discussed in the conceptual training effectiveness framework, the grayout/blackout feature requires an association cue, i.e. a cue which must be related to a specific G-load situation. Such a cue may require minimum levels of pilot experience in order for meaningful association to occur.

Arm Loaders

Arm loaders are only in the conceptual stage. Using wire attachments to the sleeves, these devices are intended to simulate increased limb heaviness under G-load condition in somewhat the same general manner as the helmet loader. As G-load increases, the wires are reeled in to increase the pull on the arm in a given direction (e.g., out away from the body or down toward the seat).

The training issues are similar to those previously discussed for other devices. Is there a benefit to be derived and, if so, does it require prior flight experience? Is the association of limb heaviness to G-loading realistic when the arms are pulled, and what scaling is appropriate for an ATD environment?

Arm loaders only have reached the conceptual stage; thus, no operational units yet have been installed. Although no research yet has focused on the device, arm loaders may be of value in training pilots to control an aircraft in high-G situations. This remains a research issue, however.

Integrated Technology

The Advanced Low Cost G-cuing System (ALCOGS) is an Air Force experimental unit intended for engineering and training research on integrated G-cuing. It incorporates G-seat, G-suit and seat shaker mechanizations into one device, which will be used to work out driving algorithms and, subsequently, training applications. The primary

purpose behind this effort is to lower the cost of the cuing package. It also is hoped that such a design will increase the continuity of cue production among system components, thus increasing the realism of the simulated G-cue environment, and, presumably, the training effectiveness of the ATD. The initial prototype is designed for use in researching many of the general issues regarding force cuing devices. It is hoped that as a research tool the ALCOGS may serve an important function in evaluating training benefits involving force cuing devices in ATD's.

RESEARCH OVERVIEW

To date, there have been no systematic or comprehensive programs of research to examine the possible training values of force cuing in ATD's. All devices in current use have been developed based on presumed rather than proved values. Existing force cuing devices have been subjectively evaluated by highly experienced pilots, rather than a cross-section of users.

The research which has been performed has little generalizability due to its simulator-specific nature. Often the lack of control and description of conditions in available research have diluted the interpretability of results. An emphasis on subjective rather than objective measures has limited the utility of results in drawing reliable conclusions. A gap in the research, which pervades simulator studies in general, deals with training effectiveness. No research was found that tested transfer of training resulting from the use of any force cuing devices.

Besides the many general shortfalls in research and experience information bases, the relationship between training objectives and force cuing devices also indicates the lack of any comprehensive research effort. Of the eight program high value flying tasks, only three have been used in force cuing device studies. These include individual and formation takeoffs and landings, aerobatics and air to air combat. Even these represent only in-simulator performance used to evaluate the efficiency of training or the realism of the ATD environment.

Further research on force cuing devices should be conducted with respect to specific training applications. Also, research should be conducted to determine the value of such devices in training common elements of various training tasks such as acceleration, deceleration, banking, etc. Conclusions regarding these common features of flight tasks could serve to streamline training through effective use of force cuing devices.

CONCLUSIONS

While it is difficult to draw solid conclusions from program site visits and the literature concerning training benefits of specific force

cuing devices or even specific force cues themselves, it can be concluded that the production of some such cues can influence certain aspects of training. The problem remains that it currently is not possible to specify those cues, much less to quantify possible benefits.

Realizing this, one general conclusion seems warranted. A comprehensive evaluation should be undertaken according to the cue utilization training effectiveness conceptual framework discussed in this report. This could provide the basic information for determining the nature and extent of benefits, if any, derived from including force cues in ATD's. Other conclusions are presented below.

Training of highly dynamic tasks (i.e., air to air combat; aerobatics; unusual attitude recognition, prevention and recovery; and low level terrain following flight) would be more apt to benefit from the use of force cuing. The value of force cues likely is very task dependent.

Seat shakers and G-seats may prove to be valid means of providing buffet, yawing and similar alerting cues arising in normal and emergency flight training situations. This remains to be proved, however.

When force cuing devices are used in conjunction with other systems, such as platform motion or out of cockpit visual systems, they must be synchronized in order to present realistic combinations of cues. The effect of not eliminating unacceptable lags could be to disorient the student and, possibly, degrade training effectiveness (See Chapter VII of this report).

G-seats may add to the subjective realism of the ATD training environment and, as a result, may increase user acceptance of ATDs.

Of the two types of motion cues, maneuver and disturbance, force cuing devices likely will be most effective in training situations involving disturbance motion.

Force cues likely are used differently by experienced and inexperienced pilots. Experienced pilots may make associations between force cues in the actual flight environment and the ATD environment that less experienced pilots cannot make. The incorporation of force cues must take into account both the nature of the task and the experience level of the students.

Training of flying tasks which do not involve highly dynamic flight elements (e.g., takeoff and landings, formation flight, air refueling, and air to ground weapon delivery) may not benefit greatly from force cuing during ATD training.

As force cuing devices are combined in an ATD, adding sustained force cues may result in progressively less training benefit. Some cues will account for the majority of the cuing value while others will be virtually ignored, depending on the task being trained.

The helmet loader device has been shown to increase smoothness of control during the transition and tracking phases of air combat in a simulator. It also adds realism to the ATD for high G-load flight regimes. Its necessity for ATD training remains unknown in terms of transfer of training.

The use of integrated technology, such as ALCOGS, may provide a cost-effective way of combining certain force cues and in the training regime.

CHAPTER VII

VISUAL AND MOTION SYSTEM INTERACTION

INTRODUCTION

The human perceives motion and orientation primarily through vision and the vestibular system. Secondarily, information about motion is obtained by cutaneous and proprioceptive receptors throughout the body. Information about body orientation and motion is obtained by the sensory systems and then integrated at higher levels of the central nervous system. Neurophysiological evidence has clearly shown a direct linkage of the visual and vestibular systems. This linkage facilitates visual perception, under normal circumstances. For the human moving about in the environment or for a pilot in contact flight (usually), visual and vestibular information is normal and compatible. However, instrument flight and ATDs often produce an information mismatch between the visual and vestibular systems. This mismatch has implications for training system design, sensory adaptation, and the positive or negative transfer of learning and adaptation to actual flight.

Ideally, ATDs would provide students with the same visual and motion cues as those experienced in actual flight. Exact duplication of motion cues obviously is impossible. The fidelity of the visual information about motion is more easily achieved than fidelity of vestibular cues, and *fortunately, the visual system tends to override the vestibular* system in most cases. It is impractical to conceive of producing accelerative fidelity in a simulator, such as a sustained 4G maneuver with rapid onset. Sophisticated wide angle visual systems are being developed for ATDs that provide rich information about pilot/aircraft orientation and movement through space. Motion platforms, by comparison, are able to provide only the most rudimentary information about the onset, direction and duration of accelerative forces acting on the pilot, particularly in intensive flight maneuvers such as air to air combat. A mismatch in the neurologically linked visual and vestibular systems will be created in an ATD to the extent that the fidelity of motion information provided by the visual display and the motion platform is unequal.

The limitations of motion platforms in ATDs occur in both acceleration level and time. Acceleration levels experienced in many flight maneuvers are far beyond simulator motion platform capability. Time limitations take at least two forms - duration of the applied force, and time lags at onset of the acceleration. By definition, accelerative forces cannot be applied to an ATD for any appreciable time without large displacements of the device in space. Therefore, motion platforms are constrained to providing accelerations of short duration. The reductions in training effectiveness due to the inability to simulate linear or angular accelerations sustained longer than a second or two are unknown. The impact on training undoubtedly varies according

to a number of variables including visual system characteristics and tasks (flight maneuvers) to be performed.

Since the duration and average levels of the acceleration are inherently limited in ATDs, the onset of the motion gains particular importance. The response of both the visual and motion systems may be delayed in ATDs (relative to actual flight) due to the time required for computation and generating the proper update information. Motion systems typically involve additional delays because of the hydraulic servos which produce simulator movement. The net effect is that some period of time elapses between a pilot's control input in a simulator and its sensory consequences in terms of the visual display system and the platform motion system (or force cuing system; see Chapter VI of this volume). Furthermore, the delays in system response may be unequal for the visual and the motion systems.

Ideally, the relationship between a pilot's control inputs and their sensory consequences (perceived changes in the pilot's environment) should closely approximate the same relationship that exists in the actual aircraft. A discrete control input in flight will cause changes perceptible to the pilot in terms of cockpit instruments, out-of-cockpit visual scene, and motion/force environment. In flight, the changes in all of these information sources are coherent and nearly simultaneous, and provide a feedback loop to the pilot regarding his control action. In an ATD, the same control input may produce changes that differ in onset, duration, and amplitude. For example, feedback asynchrony would occur if the cockpit instruments responded as quickly as in the actual aircraft while the out-of-cockpit visual scene was delayed for 100 milliseconds or more for computing and CIG update. Platform motion system responses may be delayed further, and likewise, the force cuing system (G-seat, helmet loader, etc.) responses may be delayed. A similar lack of coherence may exist subsequent to the onset of the change, such as the shortened duration and attenuated amplitude of the motion platform relative to the other information sources. The relationship between control actuation and resultant visual, vestibular, and proprioceptive changes is different in the ATD than in the aircraft. To the extent that an ATD is not just a procedures trainer, the nature of this relationship may be critical for attaining or maintaining flight skills. A related issue is that adaptation to these rearranged sensory inputs through practice in the ATD may cause difficulties when the student returns to actual flight.

Several issues for the design and use of ATDs arise: how much delay in visual or motion feedback can be tolerated before the pilot's ability to fly the simulator is compromised; how is feedback delay related to user acceptance; what disparities between visual and motion feedback will degrade flight control performance or induce simulator sickness (nausea); what are the implications for pilot in-flight performance (training effectiveness)?

The following sections address these questions by reviewing the research literature and summarizing information obtained from on-site visits. The research literature is scanty, particularly in the area of visual and motion information mismatch. Program site visits produced limited useful information on these issues, because the engineering data required to quantify delays and time lags between control inputs and feedback simply were not available. A third section discusses techniques that have been used to reduce system delays.

DELAY OF FEEDBACK

The term delay is used throughout the balance of this chapter to describe the total elapsed time from a pilot control input until the pilot receives feedback through an out of the cockpit visual display, a platform motion system, or a force cuing system. It should be noted that according to this definition, some delay will be incurred even in the actual aircraft due to actuation of control surfaces, etc. In general, shorter delays (delays most similar to the aircraft) are expected to result in improved pilot performance, better device acceptance, and reduced likelihood of simulator illness. The question is, how long of a delay can be tolerated before problems are encountered.

Clearly, aircraft dynamics and piloting control are complex issues. This makes specifying an allowable delay a complex process. Ricard and Puig (1977) reviewed available research information and combined this with "informed opinion". They concluded that simulation system delays should not exceed 83 to 125 milliseconds (msec.). Somewhat greater delays may be tolerable for certain training tasks. Riley and Miller (1978) report a study in which subjects were required to "chase" another (simulated) aircraft through a changing altitude profile. In their simulator, motion and visual system cues were highly synchronized. A fighter-type aircraft was simulated. Their data showed that a delay of up to 250 msec. was possible before performance in the altitude tracking task began to deteriorate. However, they used only two subjects in their experiment and only pitch axis control was emphasized. Ricard and Puig (1977) present data showing that delays beyond 175 msec. result in a proportional deterioration of acceptability ratings. Acceptability was rated high for up to a 175 msec. delay.

VISUAL MOTION SYNCHRONIZATION

ATDs incorporating both out of cockpit visual systems and motion cuing systems face the potential problem that cues from the two sources may not be synchronized, i.e. that cues from one source may lag behind cues from the other. If a CIG visual system is involved, then it is most likely that motion cues will lag the visual cues because of the physical inertia involved in motion systems. However, if mathematical techniques are used to reduce motion system delays, and not visual

system delays, then it is possible that visual cues could lag the motion cues.

Very little empirical data exists that can be used to develop specific guidelines on allowable synchronization, or phase differences. A general principle is that shorter time delays are generally better both in terms of performance in the ATD and in terms of user acceptance. Matheny (1974) concluded that delays as small as 100 msec. between motion and visual system information could present severe problems in terms of ATD control.

Levison (1979) has reported an experiment designed to explore the effects of motion and visual cue mismatches during training. Five groups of subjects were involved. One was trained using visual cues only; a second was trained with combined, synchronized visual and motion cues; and in the other three groups, the motion cues were delayed with respect to visual cues by 80, 200 and 300 msec. respectively. The task was to maintain a simulated fighter-like aircraft wings level in the presence of random turbulence. Their data showed that the rate at which subjects learned to control the simulation was best for the combined, synchronized cue condition followed by the 80 and 200 msec. delay conditions, and the no-motion condition. Rate of learning was poorest for the 300 msec. delay condition. These results suggest that when motion cues are delayed by 300 msec. relative to visual cues, the rate of learning was actually impaired.

It is very difficult to conclude how much delay may be tolerated between visual and motion cues and between control input and either type of cue. Experimental evidence is sketchy and desired experience-based information of the right type is not known to be available. The experimental evidence that exists involves very limited sampling of flying training tasks. And, available information does not address the issue of how much additional motion lag may be tolerable (if any) when the visual system lag is already high and approaching recommended maximums. Further, no information was found on the issue of visual cues lagging behind motion cues. Until further information is available, it is recommended that Matheny's suggestion be followed --- to strive for time delays between cues of no more than 100 msec. Based on informed opinion, motion cues should not follow visual cues by more than 125 - 150 msec. for less dynamic maneuvering, such as approach to landing; and not more than 50 msec. for highly dynamic maneuvering, such as air to air combat.

MINIMIZING DELAY PROBLEMS

Mathematical techniques exist for reducing visual and motion system delays. Ricard and Puig (1977) have described them. Details of the techniques are complicated and must be tailored to each ATD application. The general techniques are presented here so that readers are aware of their existence for use in modifying existing ATDs that may have cue

delay and synchronization problems, and for the specification and design of new ATDs.

The techniques involve compensating systems for delays by changing the driving software to take the delay's presence into account. This is much like the idea of a predictor display. The goal is to predict over the short period of time needed in computer processing of "normal" signals so that the outcome of that processing can be estimated in advance of the actual or final processing result. In other words, the techniques attempt to "leap frog" normal processing needs and estimate the effects sooner. The estimate is then updated and refined based on normal system computations, but the net effect is that delays are reduced at some minor cost in realism.

The techniques were first used to adjust motion system drive signals for actuator lags. They also have been used to compensate for timing problems introduced by the use of computer image generation (CIG) visual display systems. CIG systems require considerable processing time (currently about 100 msec.). One result has been that simulations of flying tasks requiring precision visual control of the ATD have tended to be marginally stable, with pilots occasionally introducing oscillations in the roll axis.

Attempts to reduce CIG visual system delays using mathematical compensation techniques often have resulted in an undesirable "jitter" in the visual display. Ricard, Cyrus, Cox, Templeton and Thompson (19[illegible]) reported a recent study showing that a low band pass filter could be used to further process CIG time-adjusted signals in a manner that would allow the use of prediction techniques, reduce annoying CIG "jitter", and not degrade pilot control performance. In their experiments, a filter setting between .75 and 1.0 Hertz was found workable. Whether such filter settings can be effectively used in other ATD applications must be evaluated. However, Ricard et al. have shown that the combination of prediction and smoothing seems to work, and offers a way of reducing delays and of synchronizing motion and visual cues into acceptable limits.

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APPENDIX A

CONFIGURATION AND FIDELITY DATA
INTERVIEW GUIDE

The interview guide presented in this appendix was used to guide interviews conducted during program site visits with respect to ATD fidelity, physical configuration and related information. The initial goals in using the guide were to: 1) collect information that could be related to instructor and student acceptance of a particular ATD; 2) pinpoint particular fidelity problems; and 3) establish how much fidelity might be required to accomplish certain training objectives. As discussed in Chapter II of this volume, the practice of collecting much of the information identified in this appendix was dropped, with Air Force concurrence, after initial site visits for three reasons: 1) Much of the information that was sought was not available; 2) Examination of information that could be obtained showed no relationship to ATD use or acceptance; and 3) Much of the technology surveyed was out of date by current standards, making the information questionable for future ATD designs.

TRAINING DEVICE GENERAL CONFIGURATION

1. Aircraft type and model simulated (F-4E, DC-10, etc.)
2. Training device type (CPT, OFT, etc.)
3. Training device manufacturer and date
4. In-service date
5. Number of crew position available for training in the device. Can crew positions be isolated for task-specific training? If yes, describe
6. Computer type, model number
7. Computer manufacturer and date
8. Motion system type
9. Motion system manufacturer and date
10. Visual system type
11. Visual system manufacturer and date
12. Number of instructors and console operators
13. Location of instructor/operator console

COMPUTATION TECHNICAL DESCRIPTION

1. Digital computers (separately for basic simulation, instructor station, visual system and other)
   a. Number of processors
   b. Cycle time
   c. Memory type & size
   d. Addressable memory
   e. Memory cycle time
   f. Spare memory
   g. Memory word (bit or byte orientation)

h. Peripherals (keyboard, mag tape, discs, line printer, papertape, CRT's, other terminals

i. Computer language type and efficiency

(1) Number of insturctions

(2) Boolean handlers (floating point, double precision, immediate instructions, other

j. On-line updates (list, print, change, insert, radio aids, CRT pages, other)

k. Processing (types of assembler, loading techniques, source (tapes/cards), object tapes or cards, patching capability, on-line processing/assembler)

l. I/O methods for (peripherals, linkage, instructor stations, memory to memory, weapons, other)

m. Real-time executives (type(s), interrupts, I/O handlers)

n. Diagnostics (peripheral, memory, real time, other)

2. Analog Computers

a. Reference voltage, HZs, phase

b. Power supply types

c. Types of servo amplifiers, number of servos

d. Number of spare servo slots

e. System limitation (system tolerance, amplifier frequency response, average input to output circuit delay, expansion capability)

f. Method of integration

g. Type of discrete logic capability; relay, solid state

h. Types of logic cards available (nand, and, or, servo, analogand, analog or, comparitor, microprocessors, flip flops, voltage follower, integrating amplifier, other)

i. Analog capability selected for the device

j. Would the training device be enhanced if it were interfaced to a digital computer, and how would it be enhanced?

k. Are the electronic systems modular in design with standard parts (e.g., amplifiers, motors, etc.) to facilitate interchangeability? If yes, what systems and to what extent?

MOTION SYSTEM TECHNICAL DESCRIPTION

1. Motion system type

2. Maximum motion parameters

   a. Obtain the following for pitch, roll and yaw: frequency response in seconds; maximum displacement in degrees; maximum velocity in degrees/second; and maximum acceleration in degrees/second.

   b. Obtain the following for heave, lateral displacement and longitudinal displacement: frequency response in seconds; maximum displacement in feet; maximum velocity in feet/second; and maximum acceleration in feet/second.

3. Motion cuing techniques available (stall buffet, mach buffet, turbulence, runway rumble, rough air, landing gear, landing impact, leading edge devices, speed brakes, thrust reverser, training edge flaps, G-seat, G-suit, weapon delivery effects, external stores effects, other)

4. Iteration rate in software

5. Type of control loading

6. Type of maintenance lift

7. Safety features

8. Remarks

EXTERNAL SCENE VISUAL SYSTEM TECHNICAL DESCRIPT=ION

1. a. Symbol brightness (Ft. Lamberts)

   b. Background brightness (Ft. Lamberts)

   c. Geometry (% non-linear)

   d. Heading velocity (RAD/sec.)

   e. Pitch deviation (degrees)

   f. Pitch acceleration (RAD/sec. ^{2})

   g. Roll velocity (RAD/sec.)

h. Forward velocity (knots)

i. Resolution (minutes of arc)

j. Heading deviation

k. Heading acceleration (RAD/sec.^{2})

l. Pitch velocity (RAD/sec.)

m. Roll deviation (degrees)

n. Roll acceleration (RAD/sec.^{2})

o. Vertical velocity (Ft./min.)

2. Display type

3. Display colors

4. Maximum area covered/scene

5. Scale factor

6. Maximum number of scenes

7. Maximum light points (CIG)

8. Surfaces and edges (CIG)

9. Visual parameters

10. Field of view (horizontal and vertical)

11. Image source

12. Image generation techniques

13. Iteration rates

14. Frequency response

15. Special features (e.g., area of interest display)

TRAINING DEVICE TECHNICAL DESCRIPTION

1. Quick change capabilities (engines, auto pilots, flight directors, etc.)

2. Systems and iteration rates (extent of simulation, frequency response of instruments and iteration rates, as appropriate for: fuel, air conditioning, communication, electrical, landing gear, annunciator lights, navigation, oxygen, pneumatics, fire protection, hydraulics, ice and rain, engines, flight, autopilot, avionics, radar(s), weapon system(s), and other)

3. Audio cues (engine noise, runway rumble, aero, landing gear, weapon delivery, other)

FACILITIES DESCRIPTION

1. Special building features

2. Electrical power requirements

3. Heating and air conditioning requirements

4. Maximum environment temperature equipment can operate

5. Minimum environment temperature equipment can operate

6. Hydraulic/chilled water requirements

7. Fire protection systems (interior and exterior)

8. Emergency exit features

9. Fire wall required

10. Auto shutdown features

MAINTENANCE STAFFING AND TRAINING

1. Staffing structure. (obtain the following information separately for officers, enlisted personnel, civilians and manufacturer representatives: number of positions authorized; number of people on board; areas of specialization; and functions performed.

2. How was the composition of the maintenance staff (authorized positions) derived?

3. Are present staffing levels and mixes adequate? If no, describe problems encountered.

4. On the average, how long do maintenance personnel serve this simulator before leaving for a different assignment?

5. What formal training do maintenance personnel receive before working on this simulator? (Describe)

6. What other training do maintenance personnel receive for this simulator? (Describe)

7. Describe any recurrent/proficiency training of maintenance personnel.

EQUIPMENT MAINTENANCE

1. How much time is allocated per day toward maintenance and during what time interval?

2. How is daily maintenance time typically used?

3. What preventive maintenance is performed on the following and how often? (computers, peripherals, motion system, visual system, instructor/operator station, cockpit/work station, other)

4. For this simulator, what types of maintenance are done by the following? (this organization, depot, manufacturer)

5. Who is the depot level maintenance organization for the ATD?

6. Simulator Utilization rates

   a. Source of utilization data

   b. Data for 6-month period beginning__________

   c. Hours per month scheduled to be available for training

   d. Hours per month actually available for training

   e. Hours per month used for training

   f. Hours per month scheduled for maintenance

   g. Scheduled training hours lost per month due to maintenance

7. Provisioning and Spares

   a. What directive or document establishes the type of spare parts system used?

   b. If the parts system is not specified by directive, describe the system used

   c. Problems experienced in obtaining needed spare parts

   d. Methods used to expedite obtaining parts not in stock

8. Quality Control and Fidelity

a. Who has the authority to "pull the plug" on the simulator? (for safety reasons, for training reasons, for maintenance reasons)

b. Does this simulator have to be certified as acceptable for training?

c. Who does this, and how often?

d. "Preflight" requirements and who does it?

e. Criteria used to determine whether the device is "acceptable" for training

f. How are device gripes communicated to maintenance personnel?

g. Are standardized reporting forms used? (If yes, obtain copies)

h. What type of record keeping is used to record gripes?

i. What have been the primary gripes to maintenance about this device?

j. Which gripes has the organization been able to do something about?

k. Which gripes has the organization not been able to do anything about?

l. What types of maintenance problems tend to occur repeatedly on this simulator?

m. What records are kept to record and accumulate user gripes?

n. Obtain representative mean times between failures and mean times to repair for: motion; visuals; computers; peripherals; instructor/operator console; cockpit; and other.

o. What quality control procedures are implemented after the device has been repaired?

p. What quality control procedures are used to assure "optimum" fidelity of the device?

q. What methods are used to document various parameters on a specific training device on a specific date?

r. What parameters are used to determine whether or not the device's fidelity has deteriorated?

s. How much time is allocated per month for testing the training device?

9. Maintainer Perspectives

a. Characterize maintainer general attitude about the training value of this device

b. Characterize maintainer versus instructor attitude about the value of training in this device

c. Characterize maintainer versus student attitude about the value of training in this device

d. What areas do maintainers feel are important in maintaining fidelity in order to keep the instructors happy?

e. What areas do maintainers feel are important in maintaining fidelity in order for the device to have maximum training value?

10. Is the simulator used for purposes other than training flight personnel? (Describe)

ENGINEERING OPERATIONS

1. What is the composition of the engineering staff required to update the training device?

2. How are modification requirements communicated to Engineering from the users?

3. How does the engineering group monitor aircraft changes?

4. How are modifications implemented on the training devices and how often?

5. What type training is given to engineering personnel on each device and what was the quality?

6. What quality control procedures are implemented after a modification has been made?

7. Characterize the turnover of engineering personnel involved with the device?

8. On the average, how much time is allocated per month to engineering modifications?

9. How is this engineering time utilized?

10. How are spare parts requirements established and by whom?

11. What criteria are used for acceptance and "in-service" date of the training device?

12. What personnel are used for factory testing and on-site acceptance?

13. How often are coordination meetings typically held during the device build?

14. What type of quality assurance is implemented during the build?

APPENDIX B

GLOSSARY OF TERMS

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ACUITY - A measure of the human visual system's ability to resolve detail. Maximum human acuity is accepted to be 1 minute of arc; the angle subtended by an object or separation between two objects is measured at the front of the eye.

ATD - Aircrew training device. These training media include cockpit familiarization and procedures trainers, operational flight trainers, part-task trainers, weapon system trainers and full mission trainers.

AUGMENTATION - Providing information which does not exist in the real world, or an enhancement of naturally occurring information.

CCT - Combat crew training.

CENTRAL VISION - The area of the human eye which has high acuity. Generally considered to be a circular area from 1 to 5 degrees in diameter centered on the fovea, or fixation spot of the eye.

CPT - Cockpit procedures trainer.

CT - Continuation training: training conducted routinely in operational squadrons, or proficiency training conducted periodically.

CUE - In this report, cue means some critical feature which gives important information to a pilot or other aircrew member. There is no commonly accepted definition of cue as used with respect to fidelity.

CAMERA MODEL SYSTEM - A type of image source for simulator visual systems which consists of a scale model of terrain, aircraft, or other features, and is viewed by a television camera.

COMPUTER IMAGE GENERATION (CIG) - Creation of synthetic visual images by computer processing of a numerical data base containing information about the objects and features which potentially can be part of a displayed visual scene.

CONTRAST - The relative brightness of two objects or an object and its background.

DEALY - A term applying to both visual and motion system effects. The difference in time between when a change in a simulated visual scene, movement of the cockpit or response of a force cuing device should occur and when it actually occurs.

DISPLAY CHANNEL - A complete, independent ATD visual system, except possibly for image source. Multiple display channels often are used to create large field of view visual systems.

FIELD OF VIEW - The dimensions of the area of a visual display which can be seen.

FLIGHT CHARACTERISTICS FIDELITY - The extent to which aircraft control and response characteristics are reproduced in an ATD. The extent to which the ATD "feels" like the aircraft it represents.

FLIGHT TRAINING MODEL - Patterning the way aircrew training is done in an ATD directly after the way comparable training is done in the aircraft; needlessly imposing limitations on ATD use that stem from the ways aircraft must be used for training.

FORCE CUING DEVICES - ATD mechanizations that are intended to provide onset and sustained motion-related flight cues. They include: G-seats; G-suits; seat shakers; helmet loaders; arm loaders; and visual system greyout/blackout capabilities.

FIDELITY - The extent to which cue and response capabilities in an ATD allow for the learning and practice of specific tasks so that what is learned will enhance performance of the tasks in the operational environment. Also see: physical fidelity; task fidelity; and realism.

IMAGE - The picture or scene created by a simulator visual system which is viewed by a pilot or other aircrew member.

IMAGE QUALITY - Characteristics of the appearance of an image, independent of the scene content of the image.

ISD - Instructional system development: procedural approaches to the analysis of training requirements and the development of training systems.

MOTIVATION - The degree of intent to learn or perform in a superior manner as evidenced by conscientious involvement in learning or performance.

OFT - Operational flight trainer.

PERCEPTION - The acquisition of information about the world through the human senses.

PERIPHERAL VISION - The total sensitive area of the eye surrounding the central vision area. For two eyes, the field of peripheral vision is approximately 180° horizontally by 100° vertically.

PHYSICAL FIDELITY - The degree of structural or dynamic correspondence of an ATD to the aircraft it represents.

PLATFORM MOTION SYSTEMS - ATD mechanizations that provide typically from 3 to 6 degrees of freedom of ATD cockpit movement.

PRACTICE - Deliberate participation in activities for the purpose of learning or mastering skills that depend on the thoughts and motor actions involved in the activities.

REAL IMAGE - An image actually formed in space or on a surface, such as on a projection screen or on the face of a cathode ray tube (CRT).

REALISM - The extent to which an aircrew member's experiences in an ATD correspond to experiences as they actually would occur in an aircraft under a given set of conditions. Also see physical fidelity.

RESOLUTION - The smallest separation between two objects in a display which can be detected, usually by the human eye.

RESPONSE - Any motor, perceptual or mental act by a person; generally refers to an element of an overall action as opposed to the overall action itself.

RETENTION - The capacity to remember task requirements and perform accordingly after a lapse of time during which the task has not been practiced.

SCENE CONTENT - The characteristics of a visual image in terms of what is portrayed and how things are represented, independent of image quality.

STRES - Simulator Training Requirements and Effectiveness Study.

TASK FIDELITY - The degree of correspondence of cues and responses accompanying task performance in an ATD to those characteristics of analogous performance in an aircraft.

TRAINING EFFECTIVENESS - The training benefit gained in terms of operational readiness. Also, the thoroughness with which training objectives have been achieved, regardless of training efficiency.

TRAINING EFFICIENCY - The extent to which training resources (including time) are used economically while achieving training effectiveness.

TRAINING OBJECTIVES - Precise statements of the goals of training which set forth the tasks to be performed, the performance standards to be met for each task, and the conditions under which task performance is to be demonstrated.

TRAINING REQUIREMENTS - General statements of job performance skills required for operational proficiency. Also, general statements of job performance skills that require periodic practice in order to maintain proficiency.

TRANSFER OF TRAINING - The use of skills learned in one context (e.g., an ATD) in a substantially different context (e.g., an aircraft). The carry-forward of trained performance to real world applications.

TRANSITION TRAINING - Training for aircrew members transitioning to different operational aircraft.

UPT - Undergraduate pilot training: initial pilot qualification training.

VIRTUAL IMAGE - In visual simulation, a virtual image appears to be at a greater distance than the actual display surface. A virtual image is *not* real; i.e., it does *not* exist in real space.

WST - Weapon system trainer.

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8